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Independent Research
and
Independent Exploratory Development
Programs:
FY89 Annual Report

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Independent Research and
Independent Exploratory Development Programs:
FY89 Annual Report

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San Diego, California 92152-6800

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Introduction

The Acting Technical Director encourages scientists and engineers at the Navy Personnel Research and Development Center (NPRDC) to generate new and innovative proposals to promote scientific and technological growth in the organization and the development of knowledge and technology of interest to the Navy. Support for this is provided by discretionary funding furnished by the Independent Research (IR) and Independent Exploratory Development (IED) programs of the Office of Naval Research and the Office of Naval Technology. These programs support initial research and development of interest to the Navy with emphasis on the NPRDC mission areas of the acquisition, training, and effective utilization of personnel.

Funds are provided to the Technical Directors of Navy Laboratories to support innovative and promising research and development outside the procedures required under normal funding authorization. The funds are to encourage creative efforts important to mission accomplishment. They enable promising researchers to spend a portion of their time on examining the feasibility of self-generated new ideas and scientific advances. They can provide important and rapid test of promising new technology and can help fill gaps in the research and development program. This may involve preliminary work on speculative solutions too risky to be funded from existing programs.

The funds also serve as means to maintain and increase the necessary technology base skill levels and build in-house expertise in areas likely to become important in the future. These programs contribute to the scientific base for future improvements in the manpower, personnel, and training system technology and provide coupling to university and industrial research communities.

The FY89 IR/IED programs began with a call for proposals in June 1988. Technical reviews were provided by supervisors and scientific consultants and six IR and four IED projects were funded. This report documents the results and accomplishments of these projects. Dr. W. E. Montague administers the IR and IED programs, coordinating project selection, reporting, and reviewing to assure an innovative and productive program of science and technology.

Tables 1 and 2 list the projects active during FY89 and those supported in FY90. Two papers, one IR and one IED, chosen by the Technical Director as "Best Papers of 1989" are presented. Subsequent pages contain brief reports of research progress during FY89 written by the principal investigators of each project. Appendix A lists the IR and IED projects that may have transitioned into other projects or into use by the Navy during the year. Appendix B itemizes the presentations and publications from IR and IED supported projects. Appendix C presents awards and honors related to the projects.

Table 1
Independent Research
Work Units for FY89 and FY90
(PE 0601152N)

Work Unit	Title	Principal Investigator	Internal Code	Telephone (619) 55 or AV 55	FY Funding (K)	
					89	90[a]
0601152N.R0001.01	Brain activity during visual recognition	Ryan-Jones, Lewis, Trejo, Hemmer	14	37710 37711 37711 37711	60.0	26.0
0601152N.R0001.02	Event-related potential correlates of memory performance	Williams	15	37705	60.0[b]	21.0
0601152N.R0001.03	Using diagrams for learning procedural tasks	Vogt	15	37788	40.0	40.0
0601152N.R0001.04	Analysis of tutoring in technical training	Ellis, Montague	14	39273 37849	65.0	65.0
0601152N.R0001.05	Stabilization of performance on a complex cognitive task	Federico	14	37777	12.5	0.0
0601152N.R0001.06[c]	Experienced-based career development--II	Morrison	12	39256	45.0	17.0
0601152N.R0001.07[c]	Application of machine intelligence	Sorensen	15	37782	45.0	0.0
0601152N.R0001.08	Instructional analysis	Gollub	15	37849	12.5	0.0
0601152N.R0001.09	The role of feedback in computer-based training	Cowen	14	37698	0.0	50.0
0601152N.R0001.10	An exploratory examination of neural networks as an alternative to regression	Wilkins	13	37618	0.0	30.0
0601152N.R0001.11	Neural network	Gollub	15	37849	0.0	15.0

[a]January 1990, 75 percent of funds received.
[b]Additional $40K obtained from Office of Naval Research.
[c]Transitioned.

Table 2
Independent Exploratory Development
Work Units for FY89 and FY90
(PE 0602936N)

Work Unit	Title	Principal Investigator	Internal Code	Telephone (619) 55 or AV 55	FY Funding (K) 89	90[a]
0602936N.RV36127.01	Optimization of nonlinear objectives	Krass	11	37895	50.0	.0
0602936N.RV36127.05[b]	Empirical Bayes	Boyle	11	38025	50.0	.0
0602936N.RV36127.06	Military recruit quality and the minimum wage	Nakada	15	39268	60.0	.0
0602936N.RV36127.07	Application of neural net technology to personnel loss forecasting	Huntley	11	38038	35.0	.0
0602936N.RV36127.08[b]	Developing measures of effectiveness for knowledge discovery systems	Sorensen	12	37782	.0	50.0
0602936N.RV36127.10	Decomposition methods	Thompson Krass	11	37925 37895	50.0	75.0

[a]January 1990, 75 percent of funds received.
[b]Transitioned.

Best Papers

Biography

David L. Ryan-Jones is a Personnel Research Psychologist in the Neurosciences Division at NPRDC. He received a B.S. (1973) and M.S. (1975) in Experimental Psychology from the University of Texas, El Paso, and a PhD. (1988) from Florida State University in Experimental Psychology (Psychobiology). Dr. Ryan-Jones is a member of the American Psychological Association, Human Factors Society, and the Association for Research in Vision and Ophthalmology. His research interests are in the electrophysiological correlates of perceptual and cognitive information processing.

Gregory W. Lewis was born, raised, and educated in the state of Washington. During his graduate work at Washington, he had extensive training in vision electrophysiology and neurophysiology. His doctoral dissertation was in the area of vision biometry using ophthalmic ultrasonography. From 1970 to 1974, Dr. Lewis fulfilled his military obligation as an Army officer in the U.S. Army Medical Research Laboratory, Fort Knox, Kentucky. He has been with NPRDC since 1974. He developed and currently heads the NPRDC Neurosciences Division, Training Systems Department. His research interests include the psychophysiology of individual differences, digital processing of biological signals, and physiological correlates of brain and behavior.

Biography

Leonard J. Trejo was born in Mexico City, Mexico in 1955. He performed undergraduate studies at Lock Haven State College in Pennsylvania and in 1977, he received his B.S. in psychology at the University of Oregon. He performed graduate work in psychobiology at the University of Michigan and in psychology at the University of California, San Diego, with emphasis on sensation and perception. He received the M.A. (1980) and PhD. (1982) from the University of California, San Diego for research on the neurophysiology of the pupillary light reflex and visual sensitivity loss in hereditary retinal degeneration. From 1982 to 1984, he served as Senior Fellow in the Department of Ophthalmology at the University of Washington, where he performed research on retinal toxicity, physiology of color vision, and neuroanatomy of the visual cortex. Since September 1984, he has been a Personnel Research Psychologist at NPRDC. His research interests include sensation and perception, color vision, visual pathways, cognition, and human performance.

Joan D. Hemmer is a Professor in the Psychology Department, St. Cloud State University, St. Cloud, Minnesota. She teaches psychology statistics, research methods, psychology of learning, personality theories, and general psychology. She earned her B.A. at the University of Minnesota and the M.A. and PhD. degrees at the University of Colorado at Boulder (1972). She taught psychology at the University of Massachusetts in Amherst, from 1971-1976, prior to her move to Minnesota, her home state. In 1984-1985, she trained in psychophysiology at the University of Minnesota Medical School in Minneapolis in Psychiatry Research. She was an Office of Naval Research/ American Society of Engineering Education Summer Facility Fellow at the Neurosciences Division, NPRDC, during the summers of 1988 and 1989. Her research interests are in the electrophysiological correlates of learning and performance of complex visual tasks.

Brain Activity During Visual Recognition

David L. Ryan-Jones
Gregory W. Lewis
Leonard J. Trejo
Joan D. Hemmer

Navy combat systems have become increasingly complex over the last few decades. There is a need to understand the cognitive demands placed upon the operators of these systems. One technique that can be used to estimate the cognitive demands of a task is to record the event-related electrical potentials (ERPs) generated by the brain during performance of the task. In this study, we examined the spatial and temporal distribution of ERP components during a facial recognition task. We found that familiar faces elicited significantly different ERP activity than unfamiliar faces. Although more research will be required, the results suggest this experimental technique may directly index the degree to which an individual is familiar with or has knowledge about a visual target. Potential applications may be in the areas of educational and training evaluation, personnel security and reliability assessment, and selection and classification.

Introduction

Navy combat systems have become increasingly complex over the last several decades. Many system operators depend highly upon complex visual and auditory cueing during the performance of their missions. For example, radar target acquisition systems no longer present only simple blips, but instead present very complex computer-generated symbols that cue for the important characteristics of the target, such as speed, range, altitude, and direction. These complex alphanumeric and graphical data presentation techniques may make it increasingly difficult for an operator to assimilate and interpret critical battlefield information under operational time constraints (Chechile, Eggleston, Fleishman, & Sasseville, 1989; Mitchell & Miller, 1983). Thus, the personnel operating these systems

may require cognitive skills and abilities that were not required several years ago. In contrast to the increasing complexity of operational systems, traditional selection and classification tests have not yet shown greatly improved predictive validity. These tests are able to adequately predict training or academic performance, but not on-the-job performance (Ghiselli, 1966; Vineberg & Joyner, 1982).

There is a need to improve the ability to assess the unique qualities of individuals, including their underlying perceptual and cognitive processes, and to use this improved assessment in Navy education and training programs to ensure that these individuals successfully perform their jobs once they are assigned to operational units. One factor that underlies all techniques used for personnel selection, classification, and training, as well

as on-the-job performance, is the perceptual and cognitive processing in the cerebral cortex of the brain. Neuroelectric technology, which includes the event-related brain potential (ERP), is currently one of the best methods to directly assess neural processing in individuals. The spatial and temporal sequence of cortical processing is preserved in the ERP record, from early sensory processing to complex decision-making processes to motor output, regardless of whether ERP records are analyzed as single epochs or as signal averages. Thus, the ERP is a valuable technique for studying these processes.

Objective

The general objectives of this research were to develop an understanding of the neural processes that subserve visual recognition, and to develop a reliable method for predicting which individuals will perform best in jobs in which visual recognition is a critical or substantive part of the job. The specific objective of the research reported here was to assess the spatial and temporal sequence of cortical processing initiated by viewing complex visual images. In particular, we were interested in the kinds of "real-world" visual images that Navy personnel might encounter during the performance of their duties. Job-related images could include such things as scenery, ships, airplanes, radar symbology, or human faces. We selected human faces as the initial stimuli for this study for two reasons. First, previous research has suggested that facial recognition tasks can tap a wide variety of cortical processes involved in recognition in general, from image segmentation to memory retrieval to decision making. There is some reason to believe that the neural processes underlying visual recognition are relatively independent of the nature of the stimulus. Second, there is a substantial body of

research literature on the behavioral aspects of recognition, as well as the neuroanatomical substrates of facial recognition, that allows us to identify the important experimental variables that affect recognition. Thus, it is possible to immediately begin the research with an advanced understanding of the task.

Background

Facial Recognition

The human ability to remember the face of a previously known individual is remarkable in terms of speed and accuracy. Recognition accuracy has been shown to be relatively stable over an unreinforced retention interval as long as 15 years (Bahrick, Bahrick, & Wittlinger, 1975). The ability to remember faces is affected by a wide variety of variables, including chronological age (Diesfeldt & Vink, 1989), amount of rehearsal (Proctor, 1985), context of the recognition task (Tiberghien, 1986), circumstances of the original encounter (Brown, Deffenbacher, & Sturgill, 1977), depth of processing (Bower & Karlin, 1974), complexity of the facial features (Goldstein & Chance, 1974), viewing duration (Loftus, Nelson, & Kallman, 1983; Smith & Neilsen, 1970), and image quality (Valentine, 1988). Studies have also suggested that there may be a high degree of hemispheric specialization in the processing of facial information (Young, 1984). Presentation of faces in the left half of the visual field (information processed in the right hemisphere) results in better recognition and shorter reaction time than presentation of faces in the right half of the visual field (information processed in the left hemisphere). Facial recognition has, at times, been explained in terms of a general memory processor that is independent of the nature of the material to be remembered (Paivio, 1971), a dedicated face processor

(Diamond & Carey, 1986; Perrett, Mistlin, & Chitty, 1987), and a general object processor that is independent of the nature of the objects (Cohen, 1973; Hay & Young, 1982). One widely accepted theory is that there are several different, but coexisting, systems for processing information held in memory in the human brain (Tulving, 1985), but it has not been established that the neural mechanisms underlying facial recognition are uniquely different than the neural mechanisms for the recognition of other objects.

Much of what we know about the neurophysiology of facial recognition comes from the study of those individuals afflicted with a disorder called prosopagnosia, and from studies of the responses to facial stimuli by single cortical cells in primates. Prosopagnosia is the inability to recognize familiar faces, although individuals with this deficit are generally unable to recognize other classes of objects as well (Bauer, 1986). These deficits are seen in patients who have cortical lesions near the ventromedial boundary of the temporal and occipital lobes of the brain (Damasio, Damasio, & Tranel, 1986). These lesions have been confirmed by computerized axial tomography and magnetic resonance imaging. Except in very severe cases, patients with these types of lesions do not exhibit a complete failure to recognize familiar faces. Instead, there is most often only a slight to moderate decrease in recognition accuracy, and a corresponding increase in the time to make a response. Even though the patient may deny recognizing a face, the patient may feel that the face is or should be familiar. These emotional responses, or feelings of familiarity, are believed to result from information that travels to the limbic system by way of undamaged pathways in the dorso-medial part of the parietal lobe. The exact deficits seen in prosopagnosia depend upon the location of the lesion, whether the lesion is bilateral or

unilateral, and the amount of day-to-day contact the patient has with the individuals to be recognized. In patients with unilateral lesions, the deficit is more severe if the lesion is located in the right hemisphere, supporting the behavioral finding of a right hemispheric advantage in recognition accuracy (De Haan & Hay, 1986). The deficit seems most severe in patients with bilateral lesions of the occipital-temporal region. Studies have shown that when these patients deny recognizing a familiar individual when presented with the familiar face, they still generate physiological responses, such as galvanic skin responses, that are similar to those generated by faces they do recognize. This suggests that the underlying perceptual mechanism of recognition proceeds automatically, and that the deficit is one involving the cognitive evaluation of the perceptual information (Tranel & Damasio, 1985). Thus, prosopagnosia is best viewed as a memory deficit rather than a perceptual deficit.

There have been several studies in recent years that have examined the responses to facial stimuli by cortical neurons in the superior temporal sulcus of the temporal lobe of the primate brain. These cells have sometimes been classified in terms of the aspects of the face to which they best respond, such as the full face, profile, back of head, head up, and head down (Perrett, Mistlin, Potter, Smith, Head, Chitty, Broennimann, Milner, & Jeeves, 1986). These cells are very specific in their responses to faces, and do not respond to other objects, geometrical patterns, or to emotionally arousing stimuli, and their responses are relatively independent of changes in size, orientation, and shading of the facial features. There are also other cells in this area that seem to respond to specific features on the face such as eyes or mouth. It has been proposed that the "prototypical" full

face cells would act in concert with the cells that respond to the smaller facial features to form a unique set of recognition units for each familiar individual. Thus, each familiar face would excite a particular neural template when the individual viewed the face. It should be noted that there are other cells in this area of the brain that respond to other kinds of features, so it is likely that the processing in this area is not restricted to faces.

Event-related Potentials

ERP characteristics, such as component amplitude and latency, have been used for several decades as indices of the amount and kind of information processing taking place during the performance of the experimental task. There are two sets of ERP components that have traditionally been used in studies of specific perceptual and cognitive processes. They are identified by the polarity and the latency of the component relative to the onset of the stimulus. First, there is the P1-N1-P2 complex. This consists of a positive component that occurs 70-100 msec after stimulus onset (P1), a negative component at 100-200 msec (N1), and another positive component at 200-300 msec (P2). These components seem to be related to the perceptual salience of the stimulus, and the amplitude of these components is affected by such factors as stimulus intensity, and the attention paid to the stimulus during the task (Dinges & Tepas, 1976; Hillyard & Picton, 1979). The second set of components is termed the late positive complex (LPC). This consists of a variety of positive components between 300-500 msec (P3), and a frequently positive low frequency wave, or slow wave at 500-800 msec (SW). These later components have been attributed to both the quality and the quantity of the cognitive activity taking place during the task. The amplitude of these components is affected by such factors as

stimulus intensity, probability, and meaning, as well as the complexity of the task (Duncan-Johnson & Donchin, 1982; Pritchard, 1981). In summary, there is a well-known and relatively well-understood taxonomy of ERP components that may be used in the study of the perceptual and cognitive processes taking place during facial recognition.

There have been several studies that have examined the cortical electrophysiological responses elicited during object or facial recognition tasks (Davidson, Schaffer, & Saron, 1985; Friedman, Sutton, Putnam, Brown, & Erlenmeyer-Kimling, 1988; Kok & Rooijakkers, 1985; Lang, Nelson, & Collins, 1988; Schulman-Galambos & Galambos, 1978; Small, 1986; Stuss, Picton, & Cerri, 1986). These studies have generally found that differences in waveform component amplitude and latency parallel the differences in response accuracy and latency in behavioral studies. That is, cortical ERPs waveform features seem to be affected by the same variables, such as stimulus familiarity, visual field position, and context, which affect behavioral accuracy and latency. These findings have lent support to the proposition that cortical ERPs directly index individual performance during facial recognition.

Methods

Subjects

The subjects consisted of 6 male employees of NPRDC ranging in age from 23-49 years old (mean = 35, SD = 9.19). All of the subjects had normal color vision and acuity, or had their acuity corrected to normal. Five of the subjects were right-handed, and one subject had mixed-handedness. None of the subjects reported any history of psychiatric or neurological disorders.

Stimuli

The experimental stimuli consisted of a digitized set of both familiar and unfamiliar faces, and geometric patterns. Twelve faces were created by digitizing same-size photographs in a 512 x 480 pixel format using a 16-level gray scale. The familiar faces consisted of politicians and colleagues in the lab. The faces were approximately matched for relative size, contrast (30%), and average luminance (10 cd/m^2). In addition to the basic set of 12 faces, another set of four faces was produced from two of the images (one familiar and one unfamiliar) by increasing or decreasing the contrast of each of these two faces. Thus, a total of 16 different faces were presented during the experiment. The geometric stimuli consisted of single and paired triangles, and a checkerboard pattern with a fundamental spatial frequency of about 1 cycle per degree. All of the stimuli were viewed from a distance of 1 meter, and subtended a visual angle of about 6 degrees. The subjects fixated on a small fixation point located at the center of the screen.

Recordings

Electrical activity was recorded from two occipital (O1, O2), two parietal (P3, P4), two central (C3, C4), and two frontal (F3, F4) electrode sites as defined by the International 10/20 system (Jasper, 1958) using an Electro-Cap International E1 electrode cap with tin electrodes. These sites correspond with the visual, sensory-association, motor, and frontal areas of the cortex. All sites were referenced to digitally linked mastoids with an Fz ground. Electrode impedance was reduced to less than 3000 ohms. EEG signals were amplified by Grass Model 12 amplifiers with a bandpass of 0.1-100 Hz and a gain of 20,000. One second epochs (125 msec prestimulus period and 825 msec poststimulus period) were recorded for each EEG channel, digitized at 128 Hz, and stored off-line for later analysis. Eye blinks and eye movements were detected during each epoch by the magnitude of the activity at sites F3 and F4. Epochs in which the amplitude of the activity at these sites exceeded 50 microvolts were not included in the analysis.

Procedure

After electrode application, each subject was instructed to sit comfortably at a distance of 1 meter from the display CRT and to fixate on the fixation spot. Lights in the recording room were lowered to produce an average background luminance of about 1.0 cd/m^2. Each subject was allowed to adapt for approximately 10 minutes while the experimental instructions were being read. Each subject was then presented with 30 blocks of a randomized sequence of 13 stimuli each. During each block, a total of eight faces and five geometric stimuli were viewed by the subject. The stimuli were presented for a duration of 150 msec, with an periodic interstimulus interval averaging 2000 msec. The task of the subject was to report if the face was familiar or unfamiliar, whether the single triangle was left or right of fixation, or whether the pair of triangles pointed up or down by pressing one of two keys with the right hand. After the session, each subject was asked to identify which faces were familiar or unfamiliar to the subject.

Data Analysis

For each subject, the ERP epochs were averaged for each of the 16 faces, and then averaged across the four familiar faces. The same procedure was repeated for four faces that were judged unfamiliar for all of the subjects. One of the problems in analyzing ERP data is the intersubject variability in waveform component shape. This means that it can be difficult to determine the exact

location of the peak of the component, and consequently, the latency of the component. Therefore, we chose to analyze the data by a method that allows for this variability. For every subject, the ERPs elicited in each condition were divided into 18 successive 47 msec windows from 46 msec before to 800 msec after stimulus onset. The average amplitude of the data points within each window was then calculated. Next, the differences between the average amplitude of each pair of windows for the familiar and unfamiliar conditions at each recording site, and the differences between each pair of sites for both the familiar and unfamiliar conditions were calculated. These difference scores were used as the dependent measures in the analyses. The difference scores were tested for significant deviation from zero with a t-test.

Results and Discussion

The grand average ERPs for the familiar and unfamiliar faces for one precentral site (F4) and one postcentral site (O2) are shown in Figure 1. The ERPs recorded from the frontal and central sites had similar features, and the ERPs recorded from the parietal and occipital sites had similar features. However, the ERPs recorded at the anterior sites (frontal and central) were somewhat different than the ERPs recorded at the posterior sites (parietal and occipital), particularly with respect to the very early components. This is most likely due to the functional differences of the cortical areas underlying each recording site. The ERPs recorded from the frontal and central sites for both kinds of faces were characterized by positive deflections at about 170 (P1) and 390 (P3) msec after stimulus onset, and a negative deflection at about 280 (N2) msec. In addition, the ERPs resulting from the familiar faces exhibited a late positive slow wave (PSW) with multiple peaks between 600-875

msec after stimulus onset. The ERPs recorded at the parietal and occipital sites were characterized by positive deflections at about 105 (P1), 205 (P2), and 420 (P3) msec after stimulus onset, and negative deflections at about 145 (N1) and 260 (N2) msec. In addition, there was a PSW for the familiar faces at the parietal sites with multiple peaks between 500-875 msec, and a late negative slow wave (NSW) at the occipital sites for the unfamiliar faces with multiple peaks between 600-875 msec. The latencies of these components at each site and for each condition are shown in Table 1. As has been seen in previous studies (Lewis & Froning, 1981), there was considerable individual variation in the waveform shape and component latency of the ERPs recorded at each of the sites, and not all subjects exhibited all of the components. In general, we did not analyze differences in component latency due to these large individual variations. However, there was one latency difference that was prominent across subjects. At each of the recording sites, the N2 latency was about 16 msec shorter for the unfamiliar faces than for the familiar faces.

The first factor that we examined was the difference in the windowed average amplitude of the ERPs elicited by familiar and unfamiliar faces. There were no significant amplitude differences between the ERPs elicited by the two types of faces during the prestimulus window at any of the recording sites. However, there were significant differences found at many of the poststimulus windows, and these are shown in Table 2. The number of significant differences was smallest at the frontal sites, and this number increased as the locus of recording shifted toward the posterior sites. In addition, the number of significant amplitude differences was greater at sites over the right hemisphere than at the comparable sites over the left hemisphere.

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F4

O2
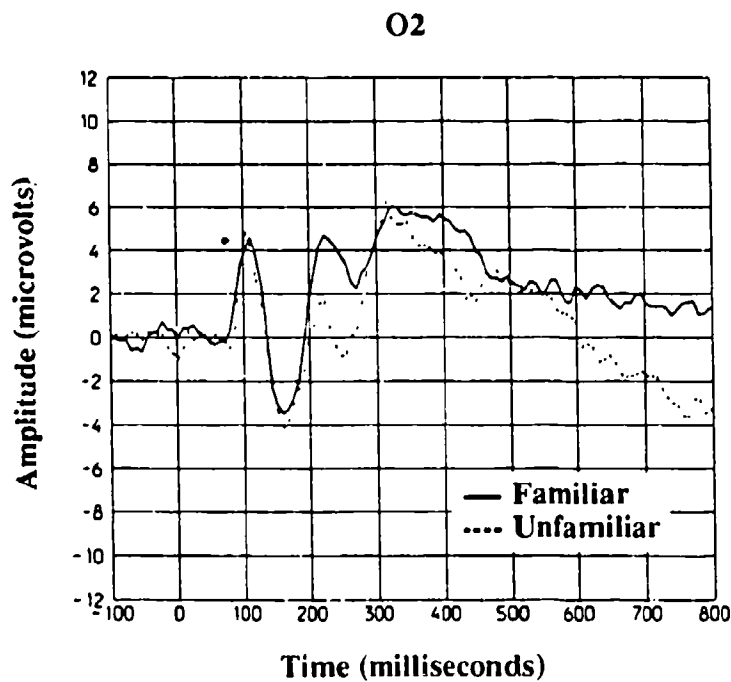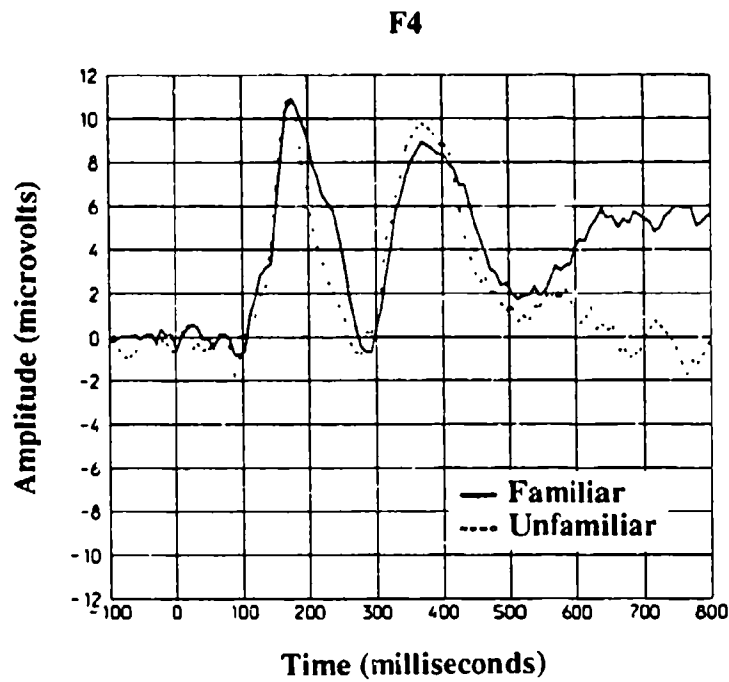
Figure 1. Grand average of ERPs elicited by familiar (solid line) and unfamiliar (broken line) faces at recording sites F4 and O2.

Table 1

ERP Component Latencies (msec.) for Recording Sites

Component	Familiar Faces								Unfamiliar Faces							
	F3	F4	C3	C4	P3	P4	O1	O2	F3	F4	C3	C4	P3	P4	O1	O2
P1	174	174	174	174	111	119	103	114	174	174	166	174	111	103	103	103
N1	--	--	--	--	143	143	143	158	--	--	--	--	135	151	158	158
P2	--	--	--	--	190	214	214	221	--	--	--	--	174	198	214	221
N2	292	292	284	284	267	277	269	269	277	277	269	269	261	261	245	253
P3	395	371	403	379	434	395	316	316	387	371	410	387	410	410	316	316
PSW	Multiple Peaks								--	--	--	--	--	--	--	--
NSW	--	--	--	--	--	--	--	--	Multiple peaks							

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Table 2

Significant Familiar-unfamiliar Windowed Average Amplitude Differences

Window #	Center (msec)	Electrode Site															
		F3		F4		C3		C4		P3		P4		O1		O2	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	-23																
2	25																
3	72																
4	119																
5	166																
6	213	--	--	--	--	--	--	--	--	3.72	0.92*	4.09	1.22*	--	--	2.53	0.74*
7	260	--	--	--	--	3.15	1.04*	3.35	1.22*	3.94	0.92**	4.41	0.41**	2.90	0.86*	3.21	0.89*
8	307																
9	354																
10	401	--	--	--	--	--	--	--	--	--	--	--	--	1.63	0.54*	1.53	0.54*
11	448	--	--	--	--	--	--	--	--	--	--	--	--	2.39	0.52**	1.96	0.68*
12	495																
13	542																
14	589																
15	636	--	--	4.57	1.59*	--	--	4.27	0.82**	--	--	3.84	0.98*	2.69	1.04*	2.82	0.70**
16	683	--	--	5.97	2.08*	--	--	4.94	1.64*	--	--	--	--	--	--	3.38	1.02*
17	730	--	--	--	--	--	--	4.56	1.70*	--	--	--	--	3.47	1.20*	3.76	1.04*
18	777	--	--	6.66	2.40*	--	--	5.96	2.04*	--	--	5.44	1.75*	4.56	0.99**	4.66	1.04

*p < .05, t > 2.571, df = 5.

**p < .01, t > 4.032, df = 5.

There were no significant differences for any of the 17 poststimulus windows at site F4. For many of the other sites, there were three regions of the ERPs that exhibited significant differences. These were at windows 6-7 (189-283 msec) for all sites except F3 and F4, windows 10-11 (377-470 msec) for the occipital sites only, and windows 15-18 (612-800 msec) for all sites except F3, C3, and P3. In all cases, the familiar faces elicited ERPs that were more positive in amplitude than those elicited by the unfamiliar faces.

The second factor that we examined was the windowed average amplitude difference between the ERPs recorded at similar pairs of recording sites. This was to determine whether or not there were any hemispheric differences in the ERPs elicited by each type of face. There were no significant hemispheric amplitude differences between the prestimulus windows in any of the conditions. However, there were significant amplitude differences at some of the poststimulus windows, and these are shown in Table 3. The number of significant differences was greater for the familiar faces than for the unfamiliar faces, and only one difference was found in the parietal region. The significant hemispheric differences were found to lie in three regions of the ERPs. These were at window 4 (95-142 msec) for the parietal-familiar and central-unfamiliar conditions, windows 7-9 (236-377 msec) for the frontal and central regions for both familiar and unfamiliar conditions, and windows 11-18 (424-800 msec) for the frontal, central, and occipital regions for the familiar faces. The ERPs recorded over the right hemisphere were more positive than the ERPs recorded at comparable sites over the left hemisphere for the frontal, central, and parietal regions, but this pattern was reversed for the occipital region.

The results provide strong support for two conclusions that have been drawn in previous behavioral studies. First, familiar and unfamiliar faces appear to be processed differently in the brain. The data also suggest that the processing networks are different, rather than a difference in the amount of processing in a single neural network. Across sites, the most consistent difference between the ERPs elicited by these two types of faces is in the amplitude of the late slow wave. The slow wave is more positive for the familiar than for the unfamiliar faces. These differences were greatest at the sites in the parietal and occipital areas of the right hemisphere. This is in line with lesion studies which have suggested that the boundary of the temporal, parietal, and occipital lobes is the site of processing during perceptual and cognitive recognition. Second, there was a distinct asymmetry in ERP amplitude seen between each of the four pairs of recording sites. This processing asymmetry was most prominent between the frontal sites, and least prominent between the parietal sites. The asymmetry was greatest for the familiar faces, and this suggests that there is hemispheric specialization of the neural networks underlying facial recognition. It should be noted that although there were large individual differences in ERP components, many of the significant differences could be seen in the ERPs for five of the six subjects.

Conclusions

This research has shown that there are measurable group differences in the waveform components of ERPs elicited by human faces based on the familiarity of the stimulus. These differences are qualitatively and quantitatively similar to the findings of previous behavioral and medical studies. The results suggest that ERPs may be a useful noninvasive technique to assess the degree of

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Table 3

Significant Left-right Hemisphere Windowed Average Amplitude Differences

| | | Familiar Faces | | | | | | | | Unfamiliar Faces | | | | | | | |
| | | Frontal | | Central | | Parietal | | Occipital | | Frontal | | Central | | Parietal | | Occipital | |
#	Center (msec)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	-23																
2	25																
3	72																
4	119	--	--	--	--	-2.18	0.54*	--	--	--	--	-0.81	0.21*				
5	166																
6	213	--	--	--	--	--		--		--	--	-2.36	0.80*				
7	260	-2.58	0.91*	-4.31	1.20*	--		--		-1.66	0.60*	-3.39	0.96*				
8	307	-3.55	0.95*	-4.98	1.20**	--		--		-2.68	0.64**	-4.17	1.04*				
9	354	-3.41	0.55**	-4.89	1.26*	--		--		-2.08	0.62**	-4.04	1.23*				
10	401																
11	448	-2.14	0.74*	--		--		--									
12	495	-1.98	0.61*	-2.70	1.00*	--		--									
13	542	--		--		--		1.80	0.53*								
14	589	-1.94	0.71*	--		--		1.59	0.52*								
15	636	-2.21	0.80*	--		--		1.51	0.42*								
16	683	-2.14	0.78*	--		--		1.26	0.43*								
17	730	-1.98	0.61*	--		--		1.08	0.38*								
18	777	-1.86	0.65*	--		--											

*p < .05, t > 2.571, df = 5.
**p < .01, t > 4.032, df = 5.

learning on tasks which involve making categorical distinctions between complex visual stimuli. This may allow direct evaluation of the effectiveness of different training techniques, or the identification those individuals who might benefit from a particular technique. An important, but not yet tapped use of this technique may be in nonverbal interrogation for personnel security and reliability assessment.

Recommendations

There is a need to continue exploratory research on this experimental paradigm within the context of the two potential applications of this technique. There are four conditions that must be met before this technique could be effectively used to make personnel and training decisions. First, it is important to establish that these differences can be seen in the ERPs elicited by different kinds of visual stimuli using different metrics of recognition. Second, it must be determined that the ERP components provide a measure of the degree to which the stimulus is known. That is, some measure of the features of the ERP must correlate with the degree of familiarity. This means that the waveform component characteristics must change during the learning process. Third, it is important to determine if correct ERP responses can be elicited from individuals whether or not they deny knowledge of the stimulus. Fourth, it must be established that the ERPs that are obtained in this paradigm can be reliably obtained under a variety of intervening conditions. Thus, the ERP would be an unbiased estimate of the familiarity of the subject.

Acknowledgments

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Biography

Iosif Krass is an Operations Research Analyst in the Manpower Systems Department at NPRDC. His research specialties are large-scale optimization and dynamic control systems. For the last 3 years, he has been developing and applying advanced techniques in operations research, computer science, and control theory to solve complex problems in Navy enlisted personnel assignment and rotation. Educated and trained in the Soviet Union as an operations research analyst, he started his research work at the Institute of Mathematics, Siberian Branch of Academy of Science, Novosibirsk, USSR (1967-1978). He received his PhD. in Applied Mathematics and Economics under supervision of Nobel Prize economist-mathematician L. V. Kantorovich and famous Russian mathematician A. A. Liapunov. After immigrating to the U.S., he was an Associate Professor at Southern Illinois and Kansas Universities (1979-1981). He also worked as a programmer consultant-analyst for Research and Development Department of Control Data Corporation in Connecticut (1981-1985). He is a member of the Operations Research Society of America. He has over 20 years of research experience and he has authored or co-authored 2 books, 29 journal articles, and 20 professional papers.

Optimization of Nonlinear Objective Functions and Dynamic Modeling in Personnel Distribution

Iosif Krass

In many problems concerning the rotation and reassignment of Navy personnel, a primary objective is the distribution balance of people by skill and pay grade across locations, types of duty, and major commands. In the Enlisted Personnel Allocation and Nomination System (EPANS), this objective was approximated heuristically. However, in developing a dynamic, long-term planning model for sea/shore rotation, there is the need for a more rigorous solution procedure. Mathematically, the distribution balancing objectives are convex nonlinear functions that should be addressed in the framework of a multiobjective optimization problem over a bounded polyhedron. The computer algorithm was developed that converges to the nonlinear optimal solution of the distribution balancing problem through linear approximation techniques that do not strongly change the original polyhedron. The algorithm is able to handle "hard requirements," such as minimum or maximum manning percentages for sea and shore duty, or minimum readiness levels for specific ships. This approach was named the "Shadow Method" because it consisted of shadowing or weighting of undesirable area of a nonlinear penalty function which should be minimized. The "Shadow Method" was successfully tested on the Navy's sea/shore rotation problem. A computer code was developed to convert the nonlinear balancing problem, using the "Shadow Method," to a linear optimization problem.

Background and Problem

In many problems concerning the rotation and reassignment of Navy personnel, a primary objective is the distribution balance of people by skill and pay grade across locations and types of duty (i.e., Continental United States, overseas, sea/shore) and major commands (i.e., Commanders-in-Chief, U.S. Atlantic and Pacific Fleets). Liang and Lee (1985) approximated this objective heuristically and Liang and Thompson (1987) implemented it in a system of computer programs, the Enlisted Personnel Allocation and Nomination System (EPANS), which reassigns enlisted personnel. Their approach is, technically speaking, a network implementation of a convex nonlinear objective function linearization. This convex function should be minimized over a polyhedron defined by a personnel distribution model. The same kind of problem arose in assessing a personnel geographic stability program by Blanco, Buletza, Liang, and Sorensen (in preparation), where the concept of "fair

share" can be mathematically reformulated as a minimization of a convex nonlinear function over a polyhedron. This "fair share" approach is rather common in the Navy. Williams and Whisman (in press) discuss the need for a "fair sharing" algorithm connected with allocating Summer Cruise slots on Navy ships to the Naval Reserve Officer Training Corps (NRC") schools. Distribution balancing, which is a version of the "fair share" concept, is also one of the goals that should be reached in allocating personnel to transitory jobs, such as recruiters and instructors (see B-K Dynamics, Inc. (1985)). The problem gets even more complicated when personnel distribution is considered for more than one planning period. For example, the sea/shore rotation problem discussed in Sorensen and Jones (1984) or Charnes and Cooper (1984) is a typical multiperiod distribution problem. This kind of problem required dynamic modeling, which can be done through network implementation, like in Charnes and Cooper (1984), or analytically, using the von Neumann approach, which is very well known in economic dynamic modeling as discussed by Morishima (1964). As it was shown in Blanco, Krass, and Louie (1988) and Krass (in press), the von Neumann approach can be successfully applied to model a sea/shore rotation problem with fixed tour lengths or with a flexible tour or credit system. Because of the dynamic nature of sea/shore rotation, it was not feasible to use the heuristic algorithm as in Lee and Liang (1985) to minimize the convex nonlinear function. We needed to develop a new approach--"shadow method" (Krass, in press). This method is a further development of the "interval" approach by Charnes and Cooper (1977) or the piecewise approximation of a convex function minimization as it is done by Danzig (1963) or Kennington and Helgason (1980). Hannan (1985) further discussed these methods of minimizing convex nonlinear functions.

Objective

The main objective of this research was to develop an improved computer algorithm that converges to the nonlinear optimal solution of a convex minimization problem which does not strongly change the original polyhedron: a network with a few side constraints. This algorithm should be able to handle "hard requirements," such as minimum or maximum manning percentages for sea and shore duty, or minimum readiness levels for specific ships. Also in the research, we will develop a systematic method for dynamic modeling of multiperiod assignment problems.

Shadow Method

This section provides the technical base for a method of solving the convex programming problem, which we called the Shadow Method.

Let

$$\varphi(y) : R^m \to R^1$$

be a convex separable function with

$$\varphi(y) = \sum_{k=1}^{m} \varphi_k(y_k). \qquad (1)$$

Let $B \subset R^n$ be a bounded polyhedron and A be an $m * n$ matrix. Consider the convex program:

$$\min \varphi(y) \qquad (2)$$

such that

$$y = Ax; \qquad (3)$$

$$x \in B. \qquad (4)$$

Assume that φ_k is a strictly convex continuous function which has first and second continuous derivatives. (These requirements can be weakened, as shown in Krass, in press). Let $[a_k, b_k] \supset \{y_k : y = (y_1, \ldots, y_k, \ldots, y_m) = Ax; x \in B\}$ and ξ_k be

the minimum of function φ_k within the segment $[a_k, b_k]$; that is,

$$\varphi_k(\xi_k) = \min_{\xi \in [a_k, b_k]} \varphi_k(\xi). \quad (4)$$

Without loss of generality, we assume that $\varphi_k'(\xi_k) = 0$ and $\varphi_k(\xi_k) = 0$.

Let $\{\delta_{ki}\}$ for $i = 1, \ldots, I_k$ be a partition of $[a_k, b_k]$ (i.e., $\delta_{k1} < \delta_{k2} < \ldots < \delta_{kI_k}$), and $\xi_k \in \{\delta_{ki}\}$. With every δ_{ki} we connect a pair of "goal" variables:

$$y_k - s_{ki}^- + s_{ki}^+ = \delta_{ki}. \quad (5)$$

We construct the following objective function by using those δ variables.

Minimize:

$$\sum_{k=1}^{m} (\sum_{\delta_{ki} \geq \xi_k} (\varphi_k'(\delta_{k,i+1}) - \varphi_k'(\delta_{k,i})) s_{ki}^- -$$
$$\sum_{\delta_{ki} < \xi_k} (\varphi_k'(\delta_{k,i}) - \varphi_k'(\delta_{k,i-1})) s_{ki}^+), \quad (6)$$

subject to conditions (3) and (5). This optimization problem we will call the δ problem.

Let $y_\delta = (y_1^\delta, \ldots, y_m^\delta)$ be a solution to the δ problem, it can be shown, that if the chosen partition $\{\delta_{ki}\}$ is rather fine, i.e.,

$$\max_{ik}(\delta_{k,i+1} - \delta_{k,i}) \leq \varepsilon. \quad (7)$$

where ε is a small positive number, then solution to δ problem will be close to a solution of the original problem.

Lemma 1

Let $s_\delta^+ = \{s_{ki}^{\delta+}\}$ and $s_\delta = \{s_{ki}^{\delta-}\}$ together with y_δ be the solution to δ problem, then

1) $s_{ki}^{\delta-} = 0$ if $y_k^\delta \leq \delta_{k,i}$; 2) $s_{ki}^{\delta+} = 0$ if $y_k^\delta > \delta_{k,i}$.

The proof of the lemma follows from the assumption of strictly convex functions φ_k, $k=1, \ldots, m$. Actually, in this case

coefficients of the linear objective function, $(\varphi_k'(\delta_{k,i+1}) - \varphi_k'(\delta_{k,i}))$ for $\delta_{ki} \geq \xi_k$ or $(\varphi_k'(\delta_{k,i}) - \varphi_k'(\delta_{k,i-1}))$ for $\delta_{ki} < \xi_k$, are positive.

For a partition $\{\delta_k\}$ defined by a sequence $\{\delta_{ki}\}$, we will refer $\Delta(\delta_k) = \max_k (\delta_{k,i+1} - \delta_{k,i})$ as a module of δ_k.

Theorem 1

Let $\delta_n = \{\delta_n^k\}$ be a sequence of partition modules which converge to 0 and y_{δ_n} be an optimal solution to the problem given in (6), (5), (3) using the partition δ_n. Then there is a sequence n_i; such that

$$y_{\delta_{n_i}} \rightarrow \hat{y} \quad (8)$$

where $\hat{y}$ is a solution of the problem (1), (2).

For a proof see Krass (in press).

Let $c_{ki} = \varphi_k'(\delta_{k,i+1}) - \varphi_k'(\delta_{k,i})$, if $\delta_{ki} \geq \xi_k$, and $\tilde{c}_{ki} = \varphi_k'(\delta_{k,i-1}) - \varphi_k'(\delta_{k,i})$, if $\delta_{ki} < \xi_k$, then the objective function to minimize in the auxiliary problem is,

$$\sum_{k=1}^{m} (\sum_{\delta_{ki} \geq \xi_k} c_{ki} s_{ki}^- + \sum_{\delta_{ki} < \xi_k} \tilde{c}_{ki} s_{ki}^+), \quad (9)$$

which is a generalization of "goal" variables method for minimization of an absolute value of a variable. (9) is also a version of the Charnes and Cooper (1977) "interval" method for convex programming.

If part of constraints in B are bounded constraints for y_k; that is,

$$e_k \leq y_k \leq d_k,$$

where $e_k, d_k \in [a_k, b_k]$ then coefficients c_{ki}, $\tilde{c}_{ki}$ in (9) for the case of $\delta_{ki} > d_k$ and $\delta_{ki} > e_k$ respectively, should be the "big M" coefficients. They guarantee that a feasible solution, if any, is within the bounded constraints given in (10).

In Figure 1 we interpret the "interval goal" programming approach (2), (5), (6) to the problem (1), (2), (3) by creating a series of penalties (shadows) which connect with partition $\{\delta_1, \ldots, \delta_6\}$. Bigger penalties (darker shadows) are located further from the minimum point $\xi = \delta_3$. Starting at point δ_6, the penalty is equal to "big M," for $x \geq \delta_6$.

Model Formulation

In the von Neumann modeling of a dynamic system, time is assumed to be discrete $t = 1 \ldots, T$, where T is the planning horizon for the optimization part of the model. The state of the model at the time t is a vector $x(t)$ in the positive orthant of n – dimensional Euclidean space: R_+^n. The trajectory in a closed von Neumann model is a sequence of state vectors $x(1), \ldots, x(T)$ such that $(x(t), x(t+1)) \in Z; t = 1, \ldots, T\text{-}1$,

where Z is the set of all feasible pair processes (technological set). The set Z, which is a subset of $R_+^n * R_+^n$, is a cone envelope of elementary processes; i.e.,

$$Z = \{(x,y) = \sum_{i=1}^{m} (a_i, b_i) \cdot u_i; \; u_i \geq 0\} \quad (11)$$

If $(x,y) \in Z$, then the input vector x can be presented as:

$$x = \sum_{i=1}^{m} a_i \cdot u_i; \quad (12)$$

and the output vector y can be presented as:

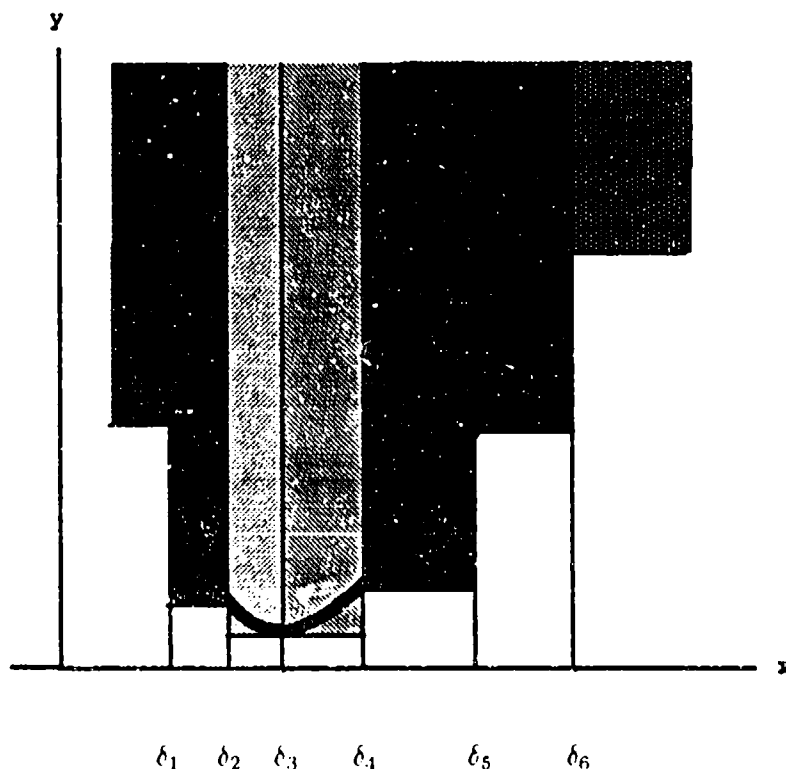$$y = \sum_{i=1}^{m} b_i \cdot u_i. \quad (13)$$

Figure 1. "Shadowing" a penalty function.

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The number u_i is called the intensity of the i-th elementary process.

To describe an open von Neumann model together with the set of elementary processes (a_i, b_i), $i = 1, \ldots, m$ we should have a set of vectors $f(t)$, $i = 1, \ldots, T$, which define interaction between the "outside" world and the model with technological set Z. A trajectory in the open model is a sequence of state vectors $x(1), \ldots, x(T)$ such that

$$(x(t), y(t)) \in Z; \qquad (14)$$

$$x(t+1) = y(t) + f(t) \geq 0. \qquad (15)$$

These relations mean that to get from the input state $x(t)$ to the output state $x(t + 1)$ we should get, first of all, to a transition state $y(t)$ which should be corrected with help of $f(t)$. This transition state should be such, that even after correction the vector $x(t + 1)$ will have all nonnegative components. For example, if $f(t)$ is vector for uncontrollable attrition and therefore $f_i(t) \leq 0$; $i = 1, \ldots, m$, then a feasible transition vector $y(t)$ should satisfy to the inequalities $y_i(t) \geq f_i(t)$; $i = 1, \ldots, m$.

The state vector $x(t)$ should describe all particular cells in the personnel distribution system. Under each cell, we model a group of people with the same parameters of interest. For example, if we were interested in studying a sea/shore rotation problem with fixed tour lengths, then a state vector $x(t) = (x_{lpq}(t))$, where $l = 1, \ldots, L$ is a location number and L is total number of locations; $p = 1, \ldots, P$ is a pay grade number and P is number of different pay grades; $q = 1, \ldots, Q$ is number of planning periods which a person with pay grade p is continuously staying in the location l, and Q is maximal number of periods which a person is allowed to stay at the same location without changing his/her pay grade.

Thus $x_{lpq}(t)$ is number of people which are staying in location l, having pay grade p and they are on this location already q planning periods. Here under location l we mean not only geographic location of a duty but also type of duty like Sea duty or Shore duty. For example, in the study of a fixed tour sea/shore rotation problem done by Blanco, Krass, and Louie (1988), there were 15 locations, $(L = 15)$ but in every cell pay grade was fixed (i. e., $P = 1$).

In the case of sea/shore rotation problem with a flexible tour or credit system the parameter q is the number of earned credits and Q is the maximum number of credits allowable in the model. In the study of the credit system by Krass (in press) in every cell pay grade was also fixed but there were only four locations $(L = 4)$. In this study, locations coincided with the composites below:

1. CONUS (Continental United States) Shore: $l = 1$;

2. CONUS Sea: $l = 2$;

3. OUTUS (Out of Continental United States) Shore: $l = 3$;

4. OUTUS Sea: $l = 4$.

We will describe elementary processes in the dynamic model assuming, like we did in both the above studies, that all persons in the model have the same pay grades. In the other words, processes of promotions or demotions are external to the model. In this case a state vector $x(t) = (x_{lq}(t) \in R_+^{L \cdot Q}$. To describe elementary processes in the model, we will introduce a unit vector $e_{lq} \in R^{L \cdot Q}$. We will begin with two basic elementary processes:

1. (e_{lq}, e_{lq+1}) - a person is staying one more period of time at the same location (in

the case of credit system this person will earn more credits);

2. $(e_{lq}, e_{l_1 1})$ - a person is rotating from location l to location l_1, beginning a duty on this new location (losing all earned credits in the case of credit system). Here we assume that $l \neq l_1$.

To avoid possible infeasible situation, we will increase the dimension of the model state by one, adding one more component $(s = L * Q + 1)$ to the model: stock outside the model with unconstrained capacity. With the help of this external stock we add one more elementary process: (e_{lq}, e_s), where e_s a unit vector in the new dimension. This process describes the situation where a person from location l being already q periods on this location (or with q earned credits in the case of credit system) is leaving the Navy. The model state $x(t)$ now is in R_+^{L*Q+1}.

In the case of a fixed tour sea/shore rotation system, we need an open model (i. e. for any time period t it can be uncontrollable influx of people to a location l from "outside world," or uncontrollable outflux from this location). In other words, there is a sequence of nonzero vectors $f(t) \in R^{L*Q}$, where $f(t) = (f_{lq})$; and, if $f_{lq} > 0$ it means that we have influx of people to a location l. In the case of influx, we assume that the inequality $f_{lq} > 0$ can hold only for $q = 1$ (i. e. new people can only begin their service on location l). On the other hand, if $f_{lq} < 0$ it means that we have outflux of people from a location l. In the case of an outflux, we assume that the inequality $f_{lq} < 0$ can hold only for $q = Q_l$, where Q_l is a regular tour time for location l.

In the case of credit system, the sea/shore rotation model consists of two parts: statistical and optimization. The statistical simulation part (described in Loffredo, Helt, and Chen (1988)) models all personnel flows external to the optimization

von Neumann model: all gains (accessions, promotions--in) and losses (demotions, promotions--out, non--retentions, retirements) to each skill/grade/composite combination. An output of this statistical simulation model is an input to the closed von Neumann model which runs two or three periods to make a new input to the statistical simulation part.

We will give more details for the optimization (von Neumann) part of the credit system because in this part we are using shadow method for nonlinear optimization. Here are some specifics of the optimization model:

1. The time interval in the model (the planning period) is 1 month. If a person remains 1 more month in the same composite, he/she will accumulate additional credit(s) to his/her sum of credits (the first elementary process in our model). Initial distribution of credits is given for each person.

2. There are no recommended tour lengths per composite but there are two credit thresholds, K_1 and K_2. If a person is at CONUS Shore ($l = 1$) and accumulated fewer than K_1 credits, then his/her rotation is undesirable (the fewer credits earned, the lesser desirability to rotate a person). If the number of accumulated credits is more than K_1, then this person is eligible for rotation (the more credits exceed K_1, the greater desirability to rotate this person).

3. Threshold K is defined in an analogous way for CONUS Sea ($l = 2$). The difference with this and the previous case is that rotation to OUTUS composites, $l = 3$ or $l = 4$, is not desirable in the current model.

4. All people who started at $t = 1$ in composite 3 or 4 and are considered to be eligible to rotate and should be rotated at the end of the month. If a person accumulates

more than K_2 credits, then it is more desirable to rotate him/her to CONUS Shore (more credits implies more desirability); in the other case it is more desirable to rotate him/her to other composites (fewer credits implies more desirability).

This phenomenon takes place in the optimization model because the statistical part of sea/shore rotation model should define number of people who should be rotated from composite 3 and 4 (those completing overseas tours). The remaining personnel in composite 3 and 4 are not subject to optimization and are only used for calculating manning levels.

5. One of the objectives is to obtain the best manning percentage balance for all composites. To formulate this goal we will introduce billets authorized, $BA(l)$, and non-rotating personnel, $CN(l)$, for every composite ($l = 1,2,3,4$). If $X_l(t)$ is the number of rotatable people in composite l at time t, then the objective to obtain the best manning percentage balance can be formulated as:

Minimize

$$\sum_{t=1}^{T} \max_{l_1,l_2=1,...,4} \left| \frac{X_{l_1}(t) + CN(l_1)}{BA(l_1)} - \frac{X_{l_2}(t) + CN(l_2)}{BA(l_2)} \right|, \quad (16)$$

where T is the time horizon. This problem is approximated as a minimization problem having objective function:

$$\sum_{t=1}^{T} \sum_{l=1}^{4} \varphi(\frac{X_l(t) + CN(l)}{BA(l)} * 100 - 100), \quad (17)$$

where $\varphi(y)$ is the special convex function discussed later (see Figure 2).

6. For every location l, we denote $P(l)$ and $p(l)$ as the maximum and the minimum manning percentage. Thus, one of the model objectives is to satisfy the following inequality:

$$p(l) \le \frac{X_l(t) + CN(l)}{BA(l)} \le P(l), \; l=1,2,3,4. \quad (18)$$

If $p(l) = 0$ or $P(l) = 0$ for some l, then the corresponding constraint is not active. Constraint (18) can also be incorporated in the shape of a penalty function $\varphi(y)$ of (17) as explained in the previous section.

Optimization Setting

As we already mentioned, the time horizon T in the optimization model is small, $T = 2$ or $T=3$. After every T steps we use the optimization model output as an input for a statistical simulation model which defines the losses and gains to each skill/grade/composite. Moreover, we use overlapping planning intervals to overcome the "boundary" effect that is common in economic dynamic planning (see Grinold (1983)). That is, we ran the optimization model for at least 1 month more than it is necessary for statistical simulation model using $x(T - 1)$ or $x(T - 2)$ as an input to the simulation model. Correspondingly, an output of statistical simulation model is an input to closed von Neumann model. Its trajectory is defined by a sequence of pairs

$$(x(t), x(t + 1)) \in Z, \; t = 1, \ldots, T - 1, \quad (19)$$

where $Z \subset R_+^{2 \cdot L \cdot Q + 2}$ is a convex cone hull of the three elementary processes described above. (Here $L = 4$, as we already mentioned).

If we denote $u_{lq}(t)$, $v_{ll_1q}(t)$, and $w_{lq}(t)$ as the intensity of the first, second, and third
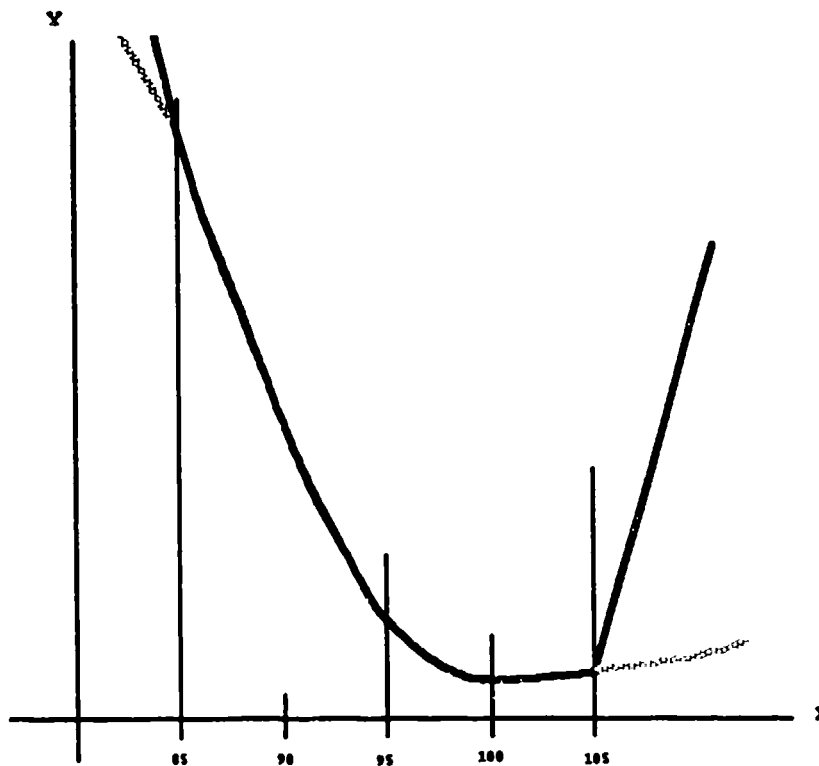
Figure 2: Penalty function $\varphi(x)$.

elementary processes, respectively, then due to the model definition we have equations

$$x_{lq}(t) = u_{lq}(t) + \sum_{l_1=1}^{4} v_{ll_{1q}}(t) + w_{lq}(t),$$
$$t = 1, \ldots, T; \qquad (20)$$

$$x_{l0}(t + 1) = \sum_{l_1=1}^{4} \sum_{q=0}^{Q} v_{l_1 lq}(t); \qquad (21)$$

$$x_{lq}(t) = u_{lq-1}(t), \text{ if } q > 1, t = 1, \ldots, T\text{-}1,$$

which define trajectory $x(t), t = 1, \ldots, T$ with initial condition

$$x_{lq}(1) = I_{lq}, \qquad (22)$$

where I_{lq} is the initial distribution of credits for composite l. This distribution should be initialized at the beginning of all system runs or coincide with an output to the simulation model after an optimization model run.

Variables $X(t)$ in (16) to (18) can be expressed as $X_l(t) = \sum_{q=0}^{Q} x_{lq}(t), t = 1, \ldots, T;$

$l = 1,2,3,4$. Due to the fifth requirement mentioned earlier in this section, we have $u_{lq}(1) = 0$ and $v_{ll_{1q}}(t) = 0$ for $l, l_1 = 3, 4$; that is, at the end of the first month all people from OUTUS composites should be rotated to CONUS composites.

From here we can see that the control of a trajectory starting from an initial distribution $\{I_{lq}\}$ can be done through the control of intensity variables $u_{lq}(t)$, $v_{ll_{1q}}(t)$, and $w_{lq}(t)$; $l, l_1 = 1,2,3,4$; $q = 1, \ldots, Q$; $t = 1, \ldots, T$. To choose a "good" trajectory, we optimize the following objective function:

$$\sum_{t=1}^{T-1} \sum_{l=1}^{4} \sum_{q=0}^{Q} (c_{lq}^1 \cdot u_{lq}(t) + \qquad (23)$$

$$\sum_{l_1=1}^{4} (c_{ll_{1q}}^2 \cdot v_{ll_{1q}}(t) + M \cdot w_{lq}(t)) +$$

$$\varphi(\frac{X_l(t) + CN(l)}{BA(l)} * 100 - 100))$$

Here, $c^1_{lq} = W_1 \cdot \tilde{c}^1_{lq}$ and

$$\tilde{c}_{lq} = \begin{cases} q - K_1 & \text{if } l = 1 \text{ and } q > K_1 \\ q - K_2 & \text{if } l = 2 \text{ and } q > K_2 \\ 0 & \text{otherwise} \end{cases}$$

Parameter W_1 is the weight of the first policy. The weight determines the level of commitment to meet thresholds K_1 and K_2. This policy will be referred as the "credit stability" policy because it gives the minimum number of credits a person should obtain before rotation. That is, he/she should not be rotated if that number has not been reached; otherwise, rotate him/her as soon as possible.

As in the case of EPANS we have a multiobjective optimization model. In the model which is presented in the next section, the "credit stability" policy is the first of four objectives. We approximate the multiobjective optimization with the help of system "nonarchimedian" weights W_l, $l = 1,2,3,4$ which define the hierarchical order between policies in a single objective optimization problem defined by equations (20) to (23).

Coefficients $c^2_{ll_1 q}$ in (23) can be expressed as $c^2_{ll_1 q} = W_1 \cdot \tilde{c}^2_{ll_1 q} + W_2 \cdot \tilde{c}^3_{ll_1}$, where

$$\tilde{c}^2_{ll_1 q} = \begin{cases} q - K_2 & \text{if } l = 2, l_1 \geq 3 \text{ and } q \geq K_1 \\ K_2 - q & \text{if } l > 2, l_1 \neq 2 \text{ and } q < K_2, \\ 0 & \text{otherwise} \end{cases}$$

and

$$\tilde{c}^3_{ll_1 q} = \begin{cases} 1 & \text{if route } l, l_1 \text{ is undesirable} \\ 0 & \text{otherwise.} \end{cases}$$

Coefficient $c^2_{ll_1 q}$ is a continuation of "credit stability" policy, which states that if a person is in CONUS Sea composite $l = 2$ and

his credits exceed CONUS Sea threshold, he/she should not be rotated to OUTUS composites. On the other hand, if a person is in OUTUS composites and has not reached the threshold, it is desirable to rotate him/her to CONUS Sea.

Coefficients $\tilde{c}^3_{ll_1}$ and weight W_2, which are associated with the second policy in our model, prohibits the use of undesirable routes; for example, route $l = 3$, $l_1 = 4$ or $l = 4$, $l_1 = 3$; that is, rotation from OUTUS to OUTUS are undesirable.

The Value M in (23) is a number which considerably exceeds any other coefficients in the model. It is the M in the "big M method." It presents a great undesirability for a person to leave the Navy in the optimization interval. Process #3, which corresponds to the intensity w_{lq}, is added to the model to avoid a problem of infeasibility of trajectories.

Finally, $\varphi(x)$ is the type of convex function described in the previous section. The function can be expressed in the form:

$$\varphi(x) = W_3 \cdot \tilde{\varphi}^1(x) + W_4 \cdot \tilde{\varphi}^2(x). \quad (24)$$

The function $\tilde{\varphi}^1(x)$ is designed to satisfy constraints (18), the policy of "meeting boundary percentage requirements." The weight W_3 reflects hierarchical importance of this policy. As indicated below, constraints (22) are not "solid"; they can be broken if weight W_3 is not big enough. The function $\tilde{\varphi}^1(x)$ is defined as:

$$\tilde{\varphi}^1(x) = \begin{cases} 0 & \text{if } x \in [p(l) \cdot 100, P(l) \cdot 100] \\ (x - P(l) \cdot 100) & \text{if } x \geq P(l) \cdot 100 \\ (p(l) \cdot 100 - x) & \text{if } x \in [0, p(l) \cdot 100]. \end{cases}$$

Clearly, if $P(l) = 0$ (i. e. composite l has no upper bound for manning percentage), then in the definition of the penalty function $\tilde{\varphi}^1(x)$ we should put $P(l) = +\infty$.

The weight W_4 and the function $\tilde{\varphi}^2(x)$ are responsible for the policy of balancing manning percentage. Function $\tilde{\varphi}^2(x)$ in Figure 2 is a convex function, where the penalty function $\varphi(x)$ is drawn in a thick line. Here, $P(l) = 1.05$ and $p(l) = .85$. The rest of function $\tilde{\varphi}^2(x)$, outside the region of $[p(l) \cdot 100, P(l) \cdot 100]$, is drawn in dotted lines. The function $\tilde{\varphi}^2(x)$ has the minimum at 100 percent, and it is shaped to force a composite to fill the manning percentage to at least 95 percent before filling composite further for the purpose of manning balancing (The corresponding curve is much steeper before 95 percent than after).

Network Representation of the Model

The described model can be presented as a network with side constraints. To describe the "network" part of the model we define a node for every triple (l, q, t), where $l = 1, \ldots, L; q = 1, \ldots, Q; t = 1, \ldots, T$. Thus, a location l at the time t will be characterize by Q nodes. Together with $L * Q * T$ nodes we define a node which we call the general stock to interpret the outside world. Equations (20) - (22) describe arc connections between nodes plus possible supply at some nodes. For example, equation (22) means that every node corresponding to a triple $(l, q, 1)$ has a supply I_{lq}. That coincides with the meaning of the value I_{lq} for the given l as initial distribution of credits for composite l. The right-hand side of (20) gives arcs connecting this node with other nodes of the model. The term $u_{lq}(1)$ represent the arc which connects the given node $(l, q, 1)$ with node $(l, q + 1, 2)$ if $q < Q$. This agrees with the definition of intensity $u_{lq}(1)$ as intensity of the process of staying one more period of

time at the same location and earning more credits. The same node $(l, q, 1)$ is connected with nodes $(l_1, q, 1)$, where $l \neq l_1$ which corresponds to the variable $v_{l_1 l q}(t)$ in (20), (21).

In Figure 3 we present a sketch of part of the network model (case $l = 1, 2$). This model is an analytical extension of the Charnes and Cooper (1984) model. In our model we set the time horizon $T = 3$. The state of the model at $t = 2$ defines the input to the simulation model whose output in turn provides an input for the next optimization run. The maximum number of credits in the implementation is: $Q = 140$, and we present results of two runs for each of the two models with $Q = 111$ and $Q = 135$. To handle the nonlinearity in the objective function (23), we use the "Shadow Method" approach which approximates problem (20) - (23) by a network with side constraints given in (5), where variables y_k are substituted by $\dfrac{X_l(t) + CN_l(t)}{BA(l)} * 100$ and $\xi_k = 100$. As shown in Theorem 1, the number of variables in (5) can be reduced in half since variable s_k^+ is not involved in the objective function (6) if $\delta_k \geq \xi_k$. Thus, (5) can be rewritten as

$$y_k - s_k^- \leq \delta_k. \tag{25}$$

However, if $\delta_k < \xi_k$, then (5) should be rewritten as:

$$y_k - s_k^+ \geq \delta_k. \tag{25}$$

To obtain a good heuristic solution, we first use NETSID code described by Kennington and Whisman (1987) to get an optimal solution of an integer--relaxed network problem with side constraints; then we round up this solution by using another set of codes prepared in Blanco, Krass and Louie (1988). Average problem size is: 500 nodes in the network with 3500 arcs (network variables), and 150 side constraints with 250 non-network variables. The execution time
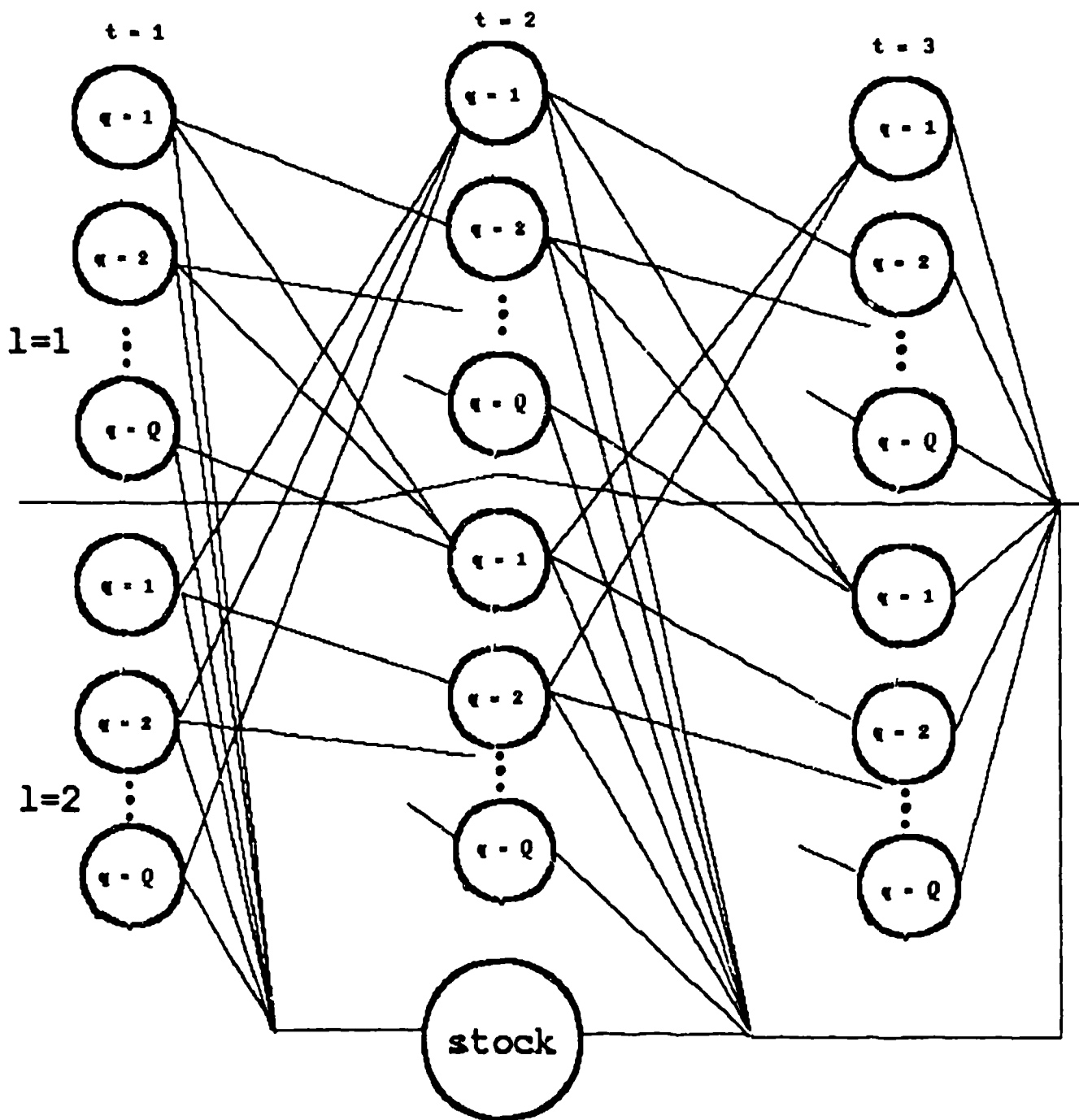
Figure 3: Part of the model network.

for the FORTRAN programs on an
IBM4341/12 is 2 to 3 CPU minutes.

Future Developments

The dynamic approach described in the
paper can be applied to many Navy
distribution and assignment problems.
Particularly, it can and should be applied to
the Navy Manning Plan, where balancing and
"fair share" fit the nonlinear concepts
discussed in this paper. The shadow method
may also prove useful in optimizing fleet
personnel readiness. As it is shown in Liang,
Krass, and Thompson (in press), unit
personnel readiness is nonlinear convex
function.

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Progress Reports

Biography

Diane Williams was born and raised in Tacoma, Washington. She did undergraduate work at the University of Washington, obtaining a B.S. in Mathematics and a B.S. in Psychology. She attended graduate school at the University of California, San Diego (UCSD), where she received her M.A. and PhD. in cognitive psychology. She received a National Institute of Health post-doctoral fellowship to do research in neuropsychology in the Boston Veterans Medical Center. From there, she returned to San Diego for a second fellowship at UCSD in electrophysiology. She came to NPRDC in 1987 where she works as a Personnel Research Psychologist in the Neurosciences Division within the Training Systems Department. Her current project is to research techniques that predict personnel reliability using behavioral and electrophysiological measures.

Diane is an adjunct faculty at University of San Diego and California School of Professional Psychology. She is a member of the American Psychological Association and an associate of the Psychonomic Society. Her research interests are in memory, electrophysiology, and neuropsychology.

Cognitive Electrophysiology

Diane Williams

Analysis of brain waves produced by subjects engaged in a memory task provides a real-time window into mental processing. This information is a valuable addition to the recall data that is typically collected in memory research. This project investigated a memory effect called the suffix effect. Subjects were asked to memorize a list of numbers while their brain waves were collected. The results provided valuable information about the typical paradigm used to investigate the suffix effect and support other findings that suggest an alternate explanation of this effect. Improvements in our ability to understand cognitive processing may lead to more efficient Navy educational and training procedures.

Research Goals

Various researchers have found that the brain waves produced by the subject while studying an item are systematically related to the subject's cognitive processing of that item. These waves can provide an index of both the subject's attention to the item and the extent of the subject's processing of items.

The Cognitive Electrophysiology Project used brain waves to supplement the information provided by the recall measures traditionally used to investigate short-term memory. These data suggest some answers to long-standing questions about mental processing in a standard short-term memory paradigm. A better understanding of the workings of memory could lead to improved predictive capabilities of success in school and job performance by providing a new capability to distinguish between people whose performance on traditional tests may be very similar.

Background

In the task, the subject is presented with a series of eight numbers and asked to recall them in order. Two effects have emerged from this line of research. These effects are called the modality and suffix effects. The modality of the presentation has a substantial effect on the subject's memory performance. When lists of numbers are presented visually or auditorily, performance is better for the auditorily presented lists. This effect is greatest for the last list items and extends back into the lists. For auditory lists, performance is nearly perfect for the last item in the lists. For the visually presented items, performance is only about 60 percent correct for the last item. The suffix effect refers to the finding that if the experimenter says anything after the presentation of an auditory list--for example, "Recall"--it impairs performance when items are presented auditorily. If the list was presented visually, the extra word does not consistently impair performance.

Despite the great quantity of research in this field, the modality and suffix effects are not well-understood. These effects were originally attributed to a hypothetical memory structure, called Precategorical Acoustic Store (PAS) by Crowder and Morton (1969). This memory was thought to contain auditory sensory information that had

not yet been categorized for semantic content. PAS accounted for the modality effect in that it offered subjects an additional source of information about the last few items in an auditory list. When an additional word was spoken after the list, the suffix was thought to overwrite the last few items in memory, thereby decreasing performance.

The PAS explanation has come under increasing criticism as the suffix effect does not appear to be confined to the auditory modality as was previously thought. The suffix effect has been found for tactile presentations, lip-read speech, and pictorial presentations. These findings have in common that information is presented over time or subjects are required to engage in prolonged uptake of information. This suggests that the failure to find a suffix effect with visual presentation may not result from the modality of presentation, but may simply reflect the different time course of information presentation. Although a spoken and written word contain equivalent information, the time course of presentation is quite different. A word takes substantially longer to hear than to read. It is possible that the processing which results from this longer auditory presentation is an important factor in producing the suffix effect.

An unusual presentation technique was used to test the hypothesis that the time course of presentation--and consequently, the time course of information uptake--is important in producing the suffix effect (Williams, 1982, 1983, 1989a, 1989b; Williams & Lewis, 1989). Words were visually presented in a manner that delayed the uptake of information. The other conditions used an auditory and a normal visual presentation. ERPs were collected to provide information about the processing of each stimulus. Electrophysiological data provide information that enables

discriminations in performance that cannot be made using any other currently available source. This information will be used to determine the nature of the processing accorded stimuli in each modality and the processing given to the suffix.

Approach

Subjects were asked to recall lists of eight digits presented sequentially in three ways while their event-related potentials (ERPs) to these stimuli were recorded. In the auditory condition, the subjects heard the digits presented using synthesized speech. In the normal visual condition, the subject's saw the word form of each number presented (e.g., "four"). In the spelled visual condition, the subjects saw the word presented with only one letter showing at a time.

The subject's ERPs were recorded while they were engaged in the memory task. These potentials are extracted from the subject's recorded ongoing brain electrical activity (or EEG) by averaging several of the segments of EEG together. These segments, or epochs, are chosen by being time-locked to the onset of the stimulus presented to the subject. When several of these segments are averaged together, a characteristic waveform emerges from the electrical activity produced by other brain activity. This waveform represents the brain's response to the presentation of a stimulus or class of stimuli within a certain instructional context. For example, if the subject is instructed to view a series of names and keep track of the number of female names, the ERPs produced by the brain's response to the names will have a characteristic shape. Further, the ERPs for the names that are recalled will be different from the ERPs for the names that were not recalled (Fabiani, Karis, & Donchin, 1986).

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Results and Discussion

The behavioral data are shown in Figure 1. A suffix effect was not obtained in the normal visual condition but was obtained both in the spelled visual presentation and in the auditory presentation. Consequently, the suffix effect is not a function of the modality of presentation, but is related to the time course of presentation. This suggests that the time course of information uptake is important in producing this effect. Differences between the effect obtained in the spelled condition and the auditory condition suggest that this temporal factor may be only one of the factors that goes into producing the auditory suffix effect.

The electrophysiological data had two main results. First, the waveforms for the trials that were followed by a suffix were different from the waveforms for the trials followed by a control stimulus--before the suffix or control had been presented. These data suggest that the standard methodology of presenting a block of trials together in each condition that will be followed by a suffix may alter the subject's processing. This lack of randomization provides extra information that allows the subject to strategically alter his or her processing during the presentation of the list items before the suffix or control has been presented. This means that the suffix and control trials are not equivalent prior to the presentation of the suffix or control stimulus. Consequently, blocking the trials together may not provide an accurate measure of the suffix effect.

The second main result is that the ERPs to the suffix and the last list item provide further support for the idea that the timing of the uptake of information is crucial in determining the suffix effect. These data are shown in Figure 2. When these data are compared for the visual condition, the

waveforms diverge early in processing. This suggests that the subject is able to differentially process the suffix in this condition. This is supported by the failure to find a suffix effect in this condition. However, when these waveforms are compared for the spelled visual condition and the auditory condition, the waveforms are much more similar. These conditions showed a suffix effect. These data suggest that the earlier the subject can differentiate the processing of the suffix, the less effect the suffix will have on his or her recall.

The other research that has shown a suffix effect for other than auditorily presented words either are presented over a few hundred millisecond interval or require up to a second of processing. This suggests that a key variable that may link these various suffix effects is the idea of information integration over time. A word that is presented visually in the normal manner can be processed quickly and consumes no additional mental resources. A word that is either presented auditorily, or is spelled, requires more time and resources before being excluded from further processing. This extra time may determine whether or not the list will show a suffix effect. The concentration of this effect on the last few items in the list may merely reflect their fragile status in memory.

Conclusions

The project obtained results which suggest that the slower time course of auditory presentation affects cognitive processing. When the same information is presented visually using a slower time course, an effect that was thought to not apply to visually presented words was obtained.

This research also provided data on a basic aspect of cognition. Performance on the type of serial learning task used to investigate
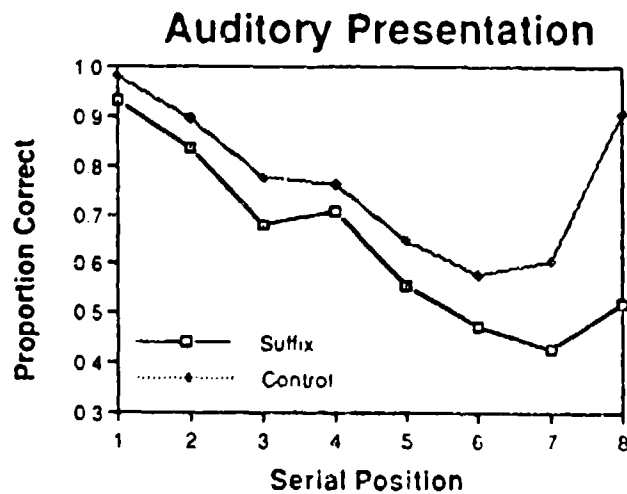
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Normal Visual Presentation

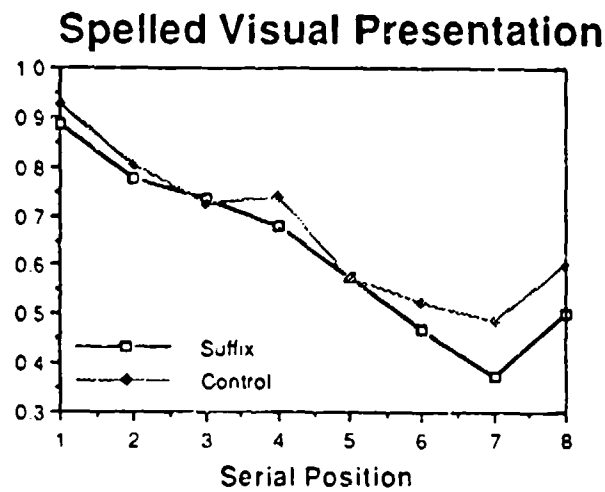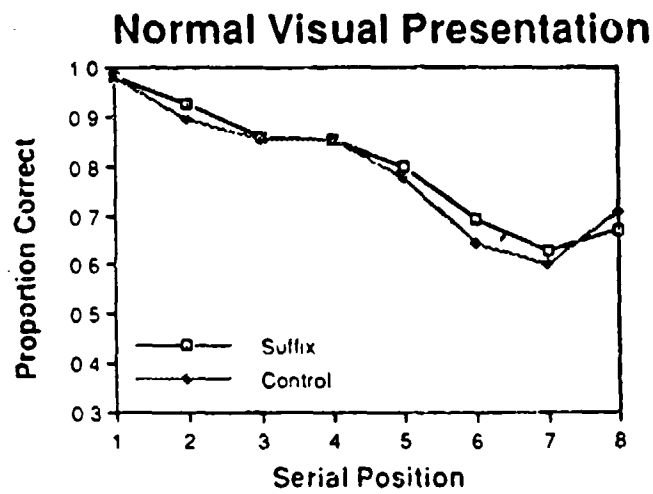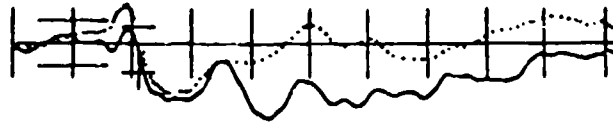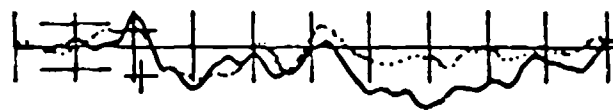# Spelled Visual Presentation

Auditory Presentation

Figure 1. Proportion correct for the normal visual presentation condition, the spelled visual presentation condition, and the auditory presentation condition.

40

Normal Visual Presentation

Spelled Visual Presentation

Auditory Presentation

...... Suffix

___ Last List Item

Figure 2. ERPs to the suffix compared with the last list item from the lists followed by a suffix. These ERPs are measured from site Cz and reflect the average of about 100 potentials. Positive is graphed down; the ticks represent 100 msec and start 100 msec before the stimulus.

the suffix effect is highly correlated (r = .66) with performance on a digit span task (Martin, 1978). Digit span is one of the subtasks that comprise the Weschler Adult Intelligence Scale, and many other intelligence and aptitude tests.

This research has also demonstrated the value of obtaining ERP measures when investigating cognitive processes. These measures can offer a converging source of data for hypotheses supported by the behavioral data as was the case with this project, or may supplement the behavioral data by suggesting distinctions that the ERPs show that may not appear in the behavioral data. The data demonstrate that ERPs can be used to determine whether situations are cognitively equivalent for subjects and to monitor the time course of information processing. ERPs may be useful in monitoring operator performance, predicting success in school, and predicting job performance. A thorough understanding of this area may provide long-range benefits to the Navy.

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Biography

Jerry L. Vogt is a Research Psychologist in the Training Technology Department, where he has been directing several projects dealing with incorporating current and emerging technologies into the automation of training materials development. He received a B.A. in psychology from Pomona College in 1970 and a PhD. in Psychobiology from the State University of New York at Stony Brook in 1975. Prior to joining NPRDC in 1985, he had been involved in university teaching, at St. John's University in Minnesota, and in basic research, at Stanford University as a NSF postdoctoral fellow. He also worked briefly for Courseware, Inc. in San Diego. His present interests include the areas of computer tools for writing, automated curriculum design and development, computer-based instruction, and the role of graphics in understanding instructional text. He has a number of publications, including two book chapters, a dozen journal articles, and several technical papers. He is a member of Human Factors Society, American Educational Research Association, and Association of Computing Machinery.

Using Diagrams for Learning Procedural Tasks

Jerry L. Vogt

Although there has been a considerable amount of recent interest in the role of illustrations for understanding instructional material, little is known about the organization of diagrams or how they interact with text to aid learning. The goal of this research is to investigate how different types of diagrams assist students in understanding instructional text so that they can better perform procedural tasks. This work involves a series of experiments looking at the effects of different diagrams upon the learning and performance of different tasks. Before any experimental studies were done, some preliminary data were gathered on the types of diagrams used in Navy training materials and their relationship to the accompanying explanatory text. These survey results revealed several points, and in particular we noted that 90 percent of the graphics in our sample of Navy training materials were line diagrams intended to show primarily the parts of a device, and that for about one-third of the graphics, the picture did not match the accompanying text. The experimental work has started with a series of experiments on the effectiveness of different types of diagrams, in particular functional (indicating the flow of information) versus representational diagrams (merely showing placement of parts). In one experiment, we found that functional diagrams produced better performance than representational diagrams for initial learning of concepts and facts about a gas turbine engine. We are currently performing additional experiments on the effects of diagram type on learning and retention, and in particular are examining the characteristics of the material retained over longer intervals.

Background

There has been a considerable amount of recent interest in the role of illustrations for understanding instructional material (e.g., Willows & Houghton, 1987a, 1987b). Beyond the general finding that text-relevant pictures enhance comprehension of the textual material (e.g., Winn, 1987; Levin Anglin, & Carney, 1987), little is known about the microstructure of diagrams (Mayer, 1989) or how they interact with text to aid learning. The goal of this research is to investigate how different types of diagrams assist students in understanding instructional text so that they can perform different types of tasks.

The instructional usefulness of diagrams can be viewed in several perspectives: as adjuncts that can assist in processing at an enhanced level; as helps for relearning procedural skills; and as helping people form mental models of device operation. Any one of these factors may help explain why a diagram alone--compared to

the text-diagram condition--produces good performance in simple procedural assembly tasks (Konoske & Ellis, 1987; Schorr & Glock, 1983). Diagrams are probably more relevant to a more complex task, such as inferring operational aspects or trouble-shooting an operational problem, where the functional understanding provided by the graphical representation helps build the appropriate mental model (Kieras & Bovair, 1984). Moreover, a diagram showing the functional operation of a device should be more effective than a diagram showing parts for teaching complex procedural tasks. The research proposed here will investigate how task performance is influenced by diagram type.

Technical Objective and Problem

The technical objective of this project is to investigate the efficiency of diagrams as adjuncts to learning procedural tasks. On the basis of a review on diagram use in Navy training materials and of the proposed experiments, guidelines for the use of diagrams in learning procedural tasks will be provided.

The development of graphic materials for Navy instructional purposes has been very expensive and time-consuming. For instance, Engineering Systems School, Great Lakes NTC has some 50;000 slides on file and it is estimated that the slides manually developed in this library cost from $100 to $300 per slide. With the introduction of computer-assisted drafting and design (CAD) technologies into the curriculum development environment, the use of slides, transparencies, and other graphic materials has become much more accessible. However, the increasing availability of graphics production tools has prompted the need for guidelines on when and how graphic representations should be used. This research concerns itself with this problem--in

particular, how and when diagrams should be used for learning procedural tasks.

Procedural tasks have been chosen because they represent a very large proportion of the sorts of skills required of technical ratings in the Navy (Wetzel, Van Kekerix, & Wulfeck, 1986). Moreover, there is good evidence that procedural tasks decline considerably, or are forgotten altogether, before they can be used on the job (Hurlock & Montague, 1982), and the use of graphic representations may assist in the long-term retention of many procedural tasks.

General Approach

This research involves a series of experiments looking at the effects of different diagrams upon the learning and performance of different tasks. Before any studies were done, some preliminary data were gathered on the types of diagrams used in Navy training materials and their relationship to the accompanying explanatory text. The purposes of this survey work were to (1) choose an appropriate domain area; (2) devise a classification scheme for diagrams, probably a representational vs. functional set of categories based on the work of Levin (Levin, Anglin, & Carney, 1987); (3) determine the prevalence of the types of diagrams (some preliminary observations indicate that representational diagrams are about twice as numerous as functional diagrams); and (4) investigate the congruence of those graphic representations with the textual material.

The experimental work is planned for two directions. One series of studies has involved rewriting, in a principled manner, the diagrams of a selection from a rate training manual, and then assessing their effectiveness in aiding recall of fact and concept learning. In the other series of

experiments, we are examining performance for either simple procedures (such as assembly of a model) or more complex procedures (such as troubleshooting) when given either representational or organizational diagrams.

Progress

The survey data has been gathered on the types of diagrams used in Navy rate training materials and their relationship to the accompanying explanatory text. In this work, which is described in detail in Vogt, Gross, and Winnifeld (1989), we surveyed the use of graphics material in Navy training manuals by systematically analyzing material for three engineering ratings. Both beginning (3 & 2) and intermediate (1 & C) rate training manuals for three engineering disciplines (Engineman, Machine Repairman, and Boiler Technician) were studied. Evaluation factors included the type, function, size, and placement of each graphic representation; we also examined the agreement between the graphic object and its accompanying text. The results indicated that 90 percent of the graphics were line diagrams intended to show the parts of a device, and that for at least 20-30 percent of the graphic presentation, the text and the picture did not match. We discuss these results in terms of improved use of graphics in training and technical manuals.

A series of experiments on the effectiveness of different types of diagrams has been started, and this work is continuing. In one experiment that has been completed, we found that functional diagrams produced better performance than representational diagrams for initial learning of concepts and facts about a gas turbine engine. Our subjects were Navy recruits awaiting assignment to "A" school, and were unacquainted with the gas turbine domain. We used a textual passage accompanied by diagrams with either functional (i.e., flow of information) labels or representational (i.e., parts) labels. While further data analysis must be done, we have found that with the functional diagrams, performance was enhanced, both for scores on a multiple choice test immediately after reading the material, and for cued recall measures taken 1 week after initial training.

Plans

We are currently performing additional experiments on the effects of diagram type on learning and retention, and, in particular, are examining the characteristics of the material retained over longer intervals. We are also starting work on performance tests where subjects are performing assembly or problem-solving tasks when given instructional materials with different sorts of diagrams. This work will be complete by the end of FY90.

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See Appendix B, p. B-2.

Biography

John A. Ellis is a Senior Research Psychologist in the Training Technology Department. He has been involved in research and development programs dealing with quality control of instructional development, criterion reference testing, cognition and instruction, computer-based training, and instructional systems design. He received his doctorate in Psychology from the University of Illinois, Champaign-Urbana in 1976. He has authored over 100 technical reports and professional publications. His current research interests are in instructional development and techniques for enhancing the retention of procedural tasks. Dr. Ellis is a member of the American Educational Research Association and the Steering Committee of the Military Testing Association. He is currently a consulting editor for the *Journal of Educational Psychology*, and is a peer review advisor for the Office for Educational Research and Improvement of the Department of Education.
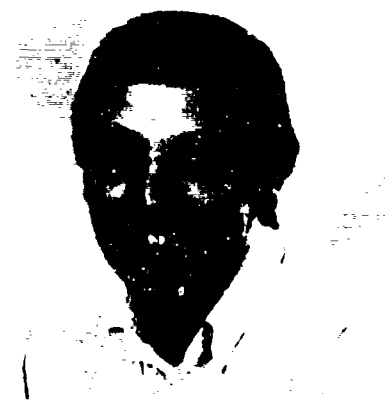
William E. Montague is a Senior Scientist in the Training Technology Department. His research specialty is cognition and learning. For several years he directed projects developing improvements of instructional design methods and using computers for training. Trained as an experimental psychologist at the University of Virginia, he did research in human factors for the Navy Electronics Laboratory, taught Psychology and Educational Psychology at the University of Illinois, and moved to NPRDC in 1972 as a project leader. He is an active member of several professional organizations including: American Educational Research Association, Cognitive Science Society, Psychonomic Society, American Psychological Association, Human Factors Society, and Military Testing Association. He has authored or co-authored over 100 professional and technical papers, and has co-edited three books concerned with instructional psychology. He is currently a consulting editor for the *Journal of Educational Psychology*, the *Journal of Applied Psychology*, the *Human Factors Journal*, and is a peer review advisor for the Office for Educational Research and Improvement of the Department of Education.

Tutoring/On-the-job Technical Training

John A. Ellis
William E. Montague

In addition to the more than 7000 formal courses taught in Navy schools, there is a considerable amount of training conducted on-the-job aboard ship. Although the Navy has courses and programs that prepare petty officers to be leaders (e.g., LMET), there is no formal training on how to be on-the-job trainers (i.e., tutors). The goal of this project is to do the basic research required to provide information for designing and developing a formal program for teaching senior Navy petty officers to be effective on-the-job trainers/tutors. The work is proceeding in four phases: (1) analysis of on-the-job training/tutoring, (2) development of a data collection methodology, (3) data collection on shipboard personnel, and (4) analysis and recommendations.

Background and Problem

In addition to the more than 7000 formal courses taught in Navy schools, there is a considerable amount of training conducted on-the-job in ship and shore based commands. In peace time, the Navy is heavily involved in training. This is especially true for new job incumbents and for those in jobs that change frequently or are difficult to master (e.g., the tasks are complex, there are infrequent opportunities for practice, etc.). Much of this training occurs informally in one-on-one or one-on-two or three situations, with a senior petty officer (e.g., E-6, E-7) working with/teaching seaman and seaman apprentice personnel on/about shipboard tasks. These senior petty officers are in effect tutors and are responsible for bringing "A" school (and non "A" school) graduates from a novice status to a journeyman. This involves preparing them to take and pass advancement exams, meet PQS and practical factor requirements, and perform their jobs.

Although the Navy has courses and programs that prepare petty officers to be leaders (e.g., LMET), there is no formal training on how to be on-the-job trainers (i.e., tutors).

Objective

The objective of this project is to do the basic research required to provide information for designing and developing a formal program for teaching senior Navy petty officers to be effective on-the-job trainers/tutors.

Approach

The project consists of four phases: (1) analysis of tutoring, (2) developing a data collection methodology, (3) data collection on shipboard personnel, and (4) analysis and recommendations.

Phase 1 involved an analysis of tutoring to determine the factors involved in tutoring and the characteristics of good tutors. Several

researchers are currently investigating these issues (Fox 1988a, b, c; Gordon, 1988) with tutors in college subjects. Phase 1 extended this work to technical training.

In Phase 2, a data collection methodology was developed for assessing tutorial skills and knowledge. The development process involved field observations and resulted in a paper and pencil survey to be administered to fleet enlisted supervisory personnel.

The questionnaire is divided into four sections. The first concerns information about personnel the respondent supervises (e.g., number, rating, "A" school graduates). The second section asks questions about the respondent's Navy training background and his opinion of the training his/her personnel have received. The third section deals with shipboard tutoring issues, and the fourth asks for demographic information on the respondent.

In Phase 3, data will be collected by mailing the questionnaire to petty officers aboard ship. The questionnaire will be analyzed in Phase 4 and recommendations will be made for a formal training program in tutoring for senior petty officers and for modifications in instructor training to enhance tutoring skills.

Progress

Phases 1 and 2 have been completed.

Plans

Phases 3 and 4 will be completed in FY90.

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Biography

Pat-Anthony Federico is a Senior Research Psychologist in the Training Technology Department. He earned his B.A. *cum laude* from the University of St. Thomas in 1965 with a double major in mathematics and philosophy and a minor in physics. He was awarded his PhD. in 1969 from Tulane University in general experimental psychology. He has research interests in individual differences in cognitive processing, learning, and performance; and computer-based instruction and performance assessment. He was elected and served as Executive Director, President, and Secretary-Treasurer of the Human Factors Society, San Diego Chapter. He is also a member of the Cognitive Science Society, Psychonomic Society, American Psychological Society, American Educational Research Association, and American Psychological Association. He is a member of the editorial advisory review board for the *Journal of Educational Psychology*, and ad hoc reviewer for *Human Factors and Memory and Cognition*. He is a peer reviewer and advisor for the Office of the Assistant Secretary for Educational Research and Improvement, United States Department of Education. He has authored or edited over 80 scientific contributions including books, chapters, journal articles, professional papers, and technical papers.

Stabilization of Performance on a Computer-based Simulation of a Complex Cognitive Task

Pat-Anthony Federico

The purpose of this research is to study the processes intrinsic to the stabilization of performance on a complex cognitive task (i.e., conducting an outer air battle). Subjects interact with an animated computer-based, graphic simulation. They allocate, deploy, and manage tactical assets in a very large number of scenarios to defend carrier-based task forces against hostile, missile-launching bombers. Concurrent and retrospective verbal protocols were obtained from the subjects regarding their battle management. Performance during each scenario was automatically assessed by the computer system against 16 multivariate measures. Cognitive and statistical analyses will be conducted to study the processes of acquiring skill and reaching stabilization of performance on this complicated mental task. Contributions to methodology and theory culminating from this research will result in improved operationally oriented performance assessment.

Background

Individuals vary in their rates and manners of skill acquisition, especially in the beginning of practice, and they reach terminal performance plateaus differentially. Early performance requires high conscious control (i.e., it is slow, sequential, effortless, limited, and directed), whereas late performance tends to be automatic (i.e., it is fast, parallel, effortless, and less limited by attentional focus). Practice during the early stages results in dramatic changes in behavior (e.g., decreasing performance variability, minimizing response time). With practice, rate of improvement diminishes and becomes more uniform across individuals (i.e., performance stabilizes). For some tasks, performance does not seem to get any better or worse and curves which reflect the rate of skill acquisition of individuals appear to be parallel (Ackerman & Schneider, 1984; Jones, 1984; Schneider, 1984). Individual variability among learners affects modes and speed of skill acquisition: Distinct experiences, cognitive models, aptitudes, and motivations can influence early and late performance differentially.

Much of the earlier research on which the above statements are based was done with psychomotor tasks. A lot less is known about complex tasks, which are primarily cognitive in nature.

Problem

Because many factors affect the nature and time course of acquisition, beginning performance on complicated tasks is usually not a good estimate of terminal performance. Since usually and initially intricate performance does not stabilize, it may reflect distinct facets of skill on different attempts to

perform as indicated above. In other words, estimates of performance are likely to measure different things on different trials for different people. Trying to separate accurately better and poorer performing people, or to determine consistently whether a trainee has mastered a needed skill become difficult. This potential lack of reliability impacts upon the predictive power of computer-based simulations for assessing operationally oriented skills. Therefore, it affects the validity of computer simulations for job-sample-performance testing in functional contexts.

Technological Objective

The technological objective of this research is to conduct cognitive and statistical analyses as well as theoretical modeling to study the process of skill acquisition resulting in the stabilization of performance on a computer-based simulation of a complex cognitive task.

General Approach

Target Task

The target task of this research consists of tactically allocating, deploying, and managing fighter and supporting aircraft to defend an aircraft carrier and its escorting ships against threatening Soviet naval air bombers. This task demands considerable practice before it can be executed with a sufficiently high level of skill and becomes automatic. For the purposes of this research, this task is considered as a test of individual differences in complex mental performance. In the execution of this task, the transition from controlled to automatic performance is important. This implies that what is crucial is not early but late performance (i.e., how well individuals do after extended practice). The administration of numerous trials on this task, together with cognitive and statistical

analyses, will make it possible to note when and how stabilization of performance is achieved (i.e., when the research subjects no longer show any tendency to improve or worsen with practice).

Computer-based Simulation

Software tools were developed for constructing computer-based animated graphic simulations of the actual radar coverage of F-14 and F/A-18 fighters and E2-C early warning aircraft as well as fuel flow of these planes together with KA-6 tankers. These include probability of kill for Phoenix, Sparrow, and Sidewinder missiles that the different fighters carry as well. The capabilities to generate an infinite number of raids from Soviet naval air bombers with ASMs (antiship missiles) in different warfare theaters and various carrier loadouts in terms of numbers of each type of fighter and missile on board enable the creation of an infinite set or universe of tactical scenarios. These were used to assess how well individuals manage outer air battles to defend carrier-based naval task forces.

Subjects

The research subjects, six F-14 pilots and radar intercept officers at NAS Miramar and/or instructors and students from the Tactical Action Officer, Tactical Warfare Overview, and/or Staff Tactical Watch Officer Courses from the Fleet Combat Training Center, Pacific were required to allocate, deploy, and manage fighter and supporting aircraft in order to knock down various numbers and mixes of hostile bombers before they reach their respective ASM launch points. Each computer-based scenario will be run in compressed or accelerated time; each threat scenario will be considered as a performance test item.

Performance Criteria

A subject's tactical performance during simulated air battles will be assessed according to 16 multivariate criteria. Some of these are as follows: the percentage of incoming threat aircraft that were detected by F-14, F/A-18, and E2-C radar systems; the percentage of bombers that fighters placed in missile LARs (launch acceptability regions); the percentage of hostile aircraft shot down or probable kills; the average range from the defended task force at which threat aircraft were knocked down; the percentage of hostile platforms knocked down before ASMs were launched, etc.

Procedure

Subjects were run on the computer-based scenarios of these symbolically displayed air battles between Soviet bombers and U.S. carrier-based aircraft. How well each allocates, deploys, and manages fighters and other supporting aircraft during the simulated battle was assessed according to the multivariate performance criteria mentioned above. The possible number of incoming raids or specific threat scenarios form a practically infinite universe. Consequently, the set of simulated tactical scenarios will be considered as an operationally oriented, domain-referenced, job-sample, performance test. With each scenario as an assessment trial, subjects will be administered 200 trials divided into 20 blocks.

Cognitive Analysis

During the first trial of every block, verbal protocols were obtained from the subjects as they conducted the simulated air battles. The analyses of these concurrent verbalizations, as well as retrospective reports, disclose the information needed by the subjects while they perform this complex task. Comparisons of the thinking-aloud protocols and retrospective reports on the first trial of every block reveal the variability in cognitive processing within as well as between subjects as they acquire skill (i.e., progress from controlled to more automatic performance of the task).

Analysis of protocols obtained early and late during practice on the task indicate how subjects' cognitive processes and structures change as their performances tend to stabilize. These will reflect the cognitive correlates of the acquisition of stable task performance. Together with a thorough componential analysis, the information obtained from the protocol analysis will be used to construct a model for performing this complex task. This model will be used to create a theoretical framework as well as build the basis of an expert system for a computer-based "intelligent tactician" that will monitor, diagnose, and assess the conduct of simulated air battles to defend carrier task forces.

Statistical Analyses

Combining statistical procedures with protocol analyses and conceptual modeling will provide an integrated account of the cognition accompanying the acquisition of complex task performance. Together with cognitive analysis and theory, statistical techniques (e.g., a test for the homogeneity of regression lines) can be used to uncover the mental processes and structures underlying the acquisition of stabilization.

Potential Products/Transition

The potential products of this research are contributions to a knowledge base and much needed theoretical framework. The contributions to methodology and theory culminating from this research can be naturally extended or transitioned to the

exploratory development of "intelligent or expert" computer-based simulation systems to measure complex cognitive performance in functional contexts. Then, the predictive power of this type of performance assessment can be determined. Likewise, this follow-on work itself can be transitioned to advanced development of an intelligent computer-based simulation system to support job-sample performance assessment of intricate cognitive tasks. This advanced system would allow the accessing of developed methodologies, theoretical orientations, mental models, as well as generic software tools to implement prescriptive procedures to aid in the production of performance tests for complex cognitive tasks.

Progress

Cognitive and statistical performance data have been collected. Verbal protocols have been transcribed, coded, and analyzed. Multivariate analyses and subsequent statistics have been computed on the performance data. Cognitive and statistical analyses are being interpreted. A manuscript documenting this research will be written.

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See Appendix B, p. B-2.

Biography

Robert F. Morrison is a Senior Scientist in the Personnel Systems Deparment who has worked at NPRDC since 1976. He was born in Minnesota and raised in Iowa. He acquired a B.S. (1952) in general science and an M.S. (1956) in applied psychology from Iowa State University. In 1962, he received a PhD. in indu ·al psychology from Purdue University. Dr. Morrison worked in human resource management, emphasizing career development for Mobil Corporation, the Mead Corporation, and Martin-Baltimore. He has headed the personnel research activity for Sun Company and his own consulting firm as well as teaching in the School of Management at the University of Toronto. His areas of research interest are management identification and the career development of managers, professionals, and scientists. His professional publications include a book, book chapters, and professional scientific articles. Dr. Morrison has won the James McKeen Cattell Award for Research Design.

Experienced-based Career Development

Robert F. Morrison

Human resource specialists need to be able to design systematically patterns of assignment that lead to the development of effective performance in positions many years after the career development process is begun. The objective of this research is to identify the steps and the time it takes an individual to master a single assignment and use this as a component in a life-span model of experiential learning. This effort provides an initial description (model) of the factors that influence how long it takes individuals to develop expertise within a specific assignment. When the research is completed, the Navy will have an algorithm to add learning time and performance level factors to the present methodology used to establish tour length. At this time, manpower and permanent-change-of-station (PCS) cost factors are the major factors considered.

Background and Problems

One hidden assumption with the growth of huge, formal education and training programs is that all efficient learning must occur in a structured (classroom-like) systematic way. Preliminary research on managerial positions challenges that assumption and indicates that the majority of learning occurs as a result of work experience (Brousseau, 1984; Campbell (personal communication) 4 January 1985; Hall & Fukami, 1979; Kanarick (personal communication) 3 April 1984; Lombardo, 1982; Morgan, Hall, & Martier, 1979; Vineberg & Taylor, 1972). While a model and propositions covering an entire career have been proposed (Morrison & Hock, 1986), the detailed attributes of its components were not adequately defined. This definition is imperative to the adequate explication of the career development process.

Since the Navy moved from pursuing its primary warfare mission in the mid-seventies to a peacetime status, the demands for its personnel, especially officers, to perform effectively in a wide variety of tasks and situations have increased markedly. A program to encourage unrestricted line (URL) officers in the development of a secondary skill (subspecialty) foundered, yet culminated in the introduction of a material professional community in 1986 in response to Congress. In 1981, the Surface Warfare Commanders Conference focused on junior officers to increase their technical skills. In 1985, Congress imposed the requirements that all officers must serve in joint assignments in order to be eligible for promotion to flag (O-7).

This plethora of demands has forced policymakers to shorten billet and command tours until they are frequently less than 18 months. Such policies have been designed using manpower flow models without considering their effect on the officers performance and career development. The fleet's personnel readiness and the effectiveness with which support activities perform are affected directly by the

opportunity that officers have to develop the capability to learn the requisite knowledge and skill of each billet and to develop them to a level of mastery. Tour lengths that are too short do not provide the opportunity to develop while ones that are too long make inefficient use of the officer force and may lower the officers motivation to perform at a high level or learn new tasks/jobs.

Objective

The broad objective of this research is to develop a generic model describing the factors that influence how long it takes an individual to develop an expert-level of skill in performing work. The specific objective is to develop, qualitatively test, and modify a preliminary model of the learning that occurs while the incumbent is in a leadership position.

General Approach

A literature search was used to identify: (1) the steps that an individual goes through in learning how to perform a job to the point of mastery; (2) the parameters that contribute to the level of performance at entry; and (3) the factors influencing what is learned and how quickly it is learned. This information was used to form an initial model of the experiential learning process.

The preliminary model was tested qualitatively via repeated interviews with 26 surface warfare department heads and 8 executive officers. Using these data, the initial model was revised (see Figure 1) and the results prepared for publication (Morrison & Brantner, 1989). Research was designed to

test a situationally specific model of experiential learning on the population of surface warfare department heads.

With the support of OP-13, SURFLANT, and SURFPAC, the research was initiated by requesting commanding officer and department head data from 322 surface ships. These data included perceptions of the factors presented in Figure 1 and of the extent to which the officers had learned their jobs regardless of how long they had been in the positions.

Plans

In FY90, the final data will be collected from the ships and analyzed using the relationships depicted in Figure 1. The results will be reported to both the surface warfare community and professional societies. If the results of the situationally specific test with surface warfare department heads are promising, the work will transition into exploratory development (6.2) to test its more general applicability across the Navy.

Expected Benefit

The Navy spends millions of dollars annually on PCS moves that are based primarily on manning and PCS cost considerations. By adding individual career development and performance factors to the decision process, the readiness of the fleet and the effectiveness with which PCS dollars are used will improve. If training proves to be a significant factor in the model, the model will provide a basis for evaluating training programs.
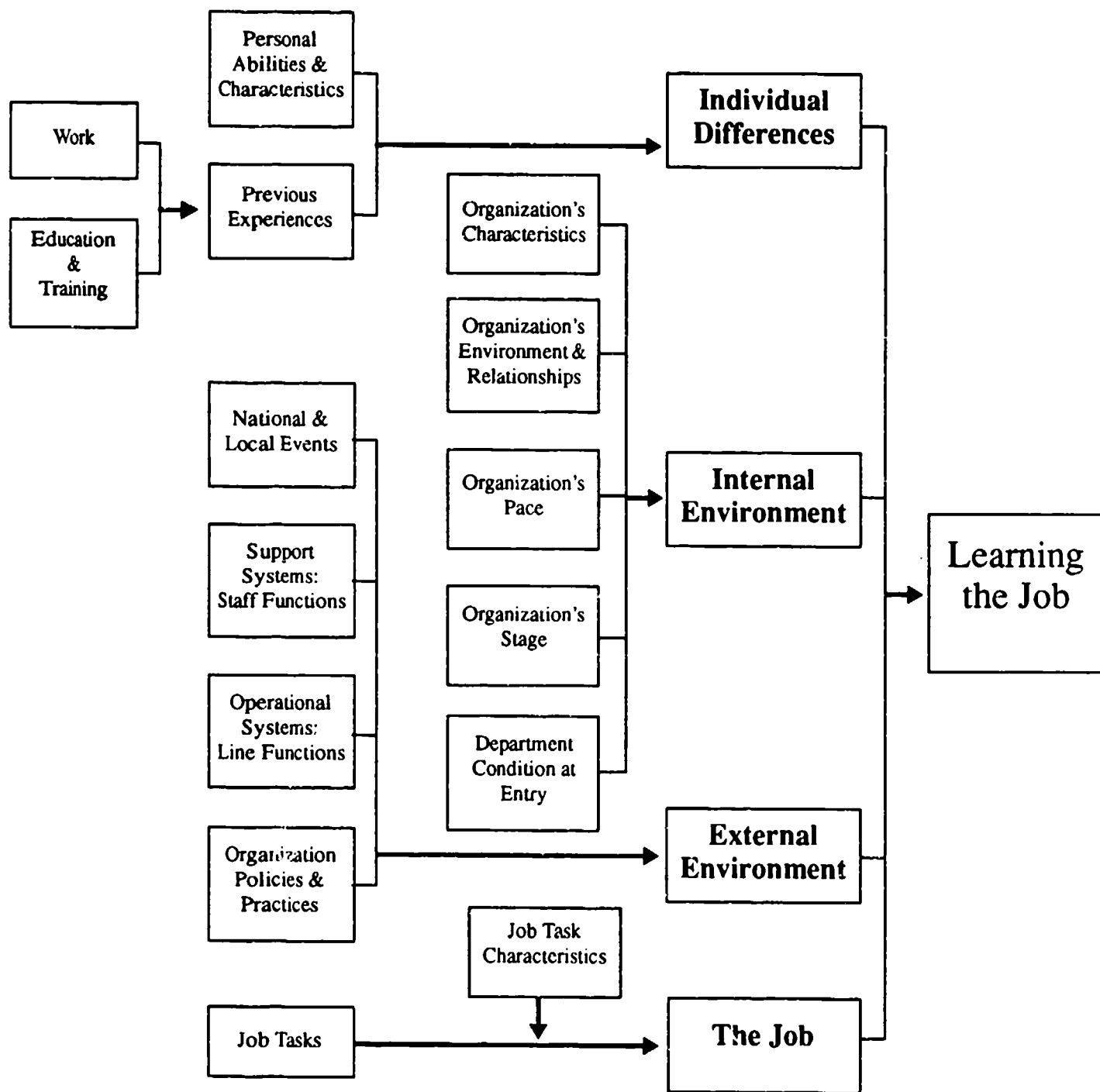
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Figure 1. Job learning model.

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Biography
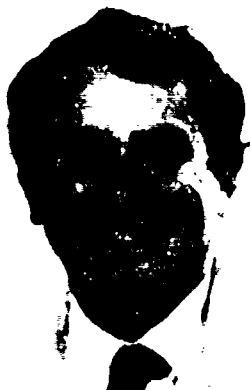
Stephen W. Sorensen is an Operations Research Analyst in the Personnel Systems Department. His current research specialty is the application of artificial intelligence to problems in the management of training. He is principal investigator of a project that applies automatic discovery systems to the analysis of large personnel and training data bases.

Trained as a mathematician and physicist, he worked as a programmer at General Dynamics Corporation in Fort Worth. He received his doctorate in operations research from the University of Texas at Austin in 1972. After 2 years as a post-doctoral fellow at Dalhousie University in Halifax, Nova Scotia, he joined NPRDC in 1974 and worked in manpower and personnel planning until 1978. From 1978 to 1983 he consulted for several companies in San Diego. He rejoined NPRDC in 1983 to work on statistical process control systems. Since 1986, he has specialized in applications of operations research to training management and implemented a planning system for NEC "C" schools.

Dr. Sorensen is a member of The Institute of Management Sciences and he has published research papers in decision analysis and machine learning. The work on this independent research project was done with Dr.'s. Clark Glymour, Richard Scheines, and Peter Spirtes from the Department of Philosophy at Carnegie-Mellon University.

Application of Machine Intelligence to Generate and Test Causal Models on Large Data Bases

Stephen W. Sorensen

Discovery systems are desired to search for relationships in large Navy manpower, personnel, and training (MPT) data bases. These discovery systems must be intelligent in model formulation, search, and evaluation. A practical test was devised to see if an existing discovery system could produce meaningful results on complex and messy Navy MPT data. The TETRAD II program, that builds causal models, was used for the test. The results indicated that discovery systems hold promise for the analysis of Navy data.

Background

Throughout the Navy there are many large data bases, each containing hundreds of data items. Users can access the data using data base management systems, statistical packages and prc ams written for a specific application. A ty ical data base is NPRDC's TRAINTRACK, a cohort data base containing training incidents of Navy enlisted personnel. TRAINTRACK contains 63 data elements and over 1,400,000 records and occupies over 650 megabytes of disk space. TRAINTRACK can be used to test policies about school pipelines, individual training histories, and the utilization of training.

The problem with applying traditional software analysis packages to very large data bases is an implicit assumption that the analyst will exhaust all models relevant to the posed problem. For at least three reasons, this is a shaky assumption: (1) most human-generated models involve a limited subset of variables, (2) inevitable human bias as to the relevant variables will constrain the search, so in very large data bases many stable and potentially useful relationships never get tested, and (3) the process of checking a model is labor-intensive: the model must be formed, the data elements must be restructured (i.e. combined, normalized, scaled, factorialized, etc.), the test made, and the test results analyzed. This entire cycle must be repeated for every model.

What is needed are means to generate meaningful models, use a search mechanism constrained only by criteria of statistical replicability and causal interpretability, and report only relationships that are both interpretable and actionable. The software must have intelligence in model formation, search, and evaluation. The technology would be useful not only for Manpower, Personnel, and Training (MPT) data bases but also for any large Navy data base. Discovery systems, such as those described by Langley, Simon, Bradshaw, and Zytkow (1987) may be able to generate these models.

Objective

This project used an existing discovery program to automatically search for causal

models in two Navy data bases. The discovery method should be effective because it can repeatedly examine relationships while a person is restricted to only a few attempts. However, Navy data is often complex and messy; therefore, a practical test was necessary to determine the feasibility of the discovery approach.

Approach

The TETRAD II program (Glymour, Scheines, Spirtes, & Kelly, 1987; Spirtes, Scheines, & Glymour, in prepartion) has shown promise in discovering causal structure in non-experimental data. Two data sets were developed for the tests. In the first, the TETRAD II program searched for causes of attrition and setback in the Navy's air traffic control (AC) school pipeline. The data for the study was taken from the TRAINTRACK file and the Survival Tracking File. NPRDC arranged the data and calculated the necessary covariance matrices for the program. The program was run at Carnegie-Mellon University.

For a second data set, NPRDC used results of a survey that collected opinions on the recruiters' quality of life with particular emphasis on the demands of their jobs. The survey's ultimate goal was to construct models to change policy and improve the effectiveness of recruiting. NPRDC scaled and arranged the data for use in TETRAD II. The program was run at Carnegie-Mellon to obtain causal models on the recruiters' job satisfaction and effectiveness.

Results

The discovery methods have been effective on the Navy's data. In a simple initial trial, TETRAD II was able to discover the components from the Armed Service Vocational and Aptitude Battery (ASVAB) that make up the Armed Forces Qualifying

Test (AFQT) scores. The program was given seven ASVAB scores for the individuals in the AC data, but only three of the scores are used in AFQT. In spite of likely common causes in the test scores, TETRAD II correctly picked the three ASVAB components.

In a more complicated trial, TETRAD II was asked to predict an outcome variable (non-academic failure, academic failure, or pass) from the following input variables: AFQT, number of academic setbacks; years of education; ASVAB score on mechanical comprehension; ASVAB score on mathematical knowledge, gender, length of service, and number of interruptions of training. Unfortunately, the explanatory variables accounted for only about 10 percent of the variance of the outcome variable and the model did not seem useful.

An alternative problem used the outcome variable as a classification and the goal was to minimize misclassification. TETRAD II's model gave good insight into how misclassifications occur. Using the model, it was shown that by restricting admission criteria and training schedule, the Navy might reduce academic and non-academic failures from 34.5 percent to 20 percent. Practical applications depend on getting enough applicants for AC training that meet the restrictions.

Further tests are being run with the AC data set and the recruiter data set.

Plans

The results from this project were encouraging for applications of discovery methods. The 6.1 project's results will be used in the 6.2 project *Training Management Expert Systems*.

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See Appendix B, p. B-2.

Biography

James P. Boyle is a statistician in the Manpower Systems Department at NPRDC. He was trained in Mathematics and Statistics at the University of Missouri, receiving a PhD. in Statistics in 1984. His research interests include empirical Bayes estimation and force management forecasting models. He is presently a member of the American Statistical Association.

Loss Forecasting With Empirical Bayes Estimators

James P. Boyle

Manpower planners within the Navy and Marine Corps require accurate personnel loss forecasts to generate executable personnel plans. Traditionally, the method of least squares has been a popular method of estimating parameters in loss forecasting models. In recent years, a group of statistical techniques known as empirical Bayes methods have emerged as competitors to the least squares approach. This research effort was designed to test the hypothesis that empirical Bayes estimators generate more accurate loss forecasts than standard least squares estimators.

Background and Problem

Military manpower systems are "vacancy driven." New personnel are recruited and current personnel are promoted when vacancies are created by various types of personnel losses. Plans to achieve targeted end-strengths and satisfy budget constraints are good only if projected losses come close to actual losses. Effective force planning depends heavily on accurate loss forecasts.

While there is a wide variety of loss forecasting models in use, the models can be grouped broadly into two categories-- reflecting quite different viewpoints. The first group consists of time series models that assume future losses and are entirely a function of past loss behavior. The second group, comprised of econometric models, explain future loss behavior in terms of exogenous variables (e.g., military compensation, civilian employment conditions).

Although different in spirit, the two approaches share a common characteristic.

Both contain parameters that must be estimated before any forecasts can be obtained. A popular method of estimating these parameters has been least squares.

However, in recent years, the popularity of least squares has been challenged by a set of techniques known as "empirical Bayes" methods. The emergence of these "empirical Bayes" methods is due largely to a series of papers published by Bradley Efron and Carl Morris from 1972 to 1977. These papers contain both theoretical and empirical results recommending empirical Bayes estimators over least squares estimators. A book by G. G. Judge and M. E. Bock (1978), which develops empirical Bayes estimators in the General Linear Model, and a recent article by George Casella (1985) also confirm the superiority of empirical Bayes estimators.

Objective

The objective of this research was to test the hypothesis that empirical Bayes estimators of parameters in loss forecasting models lead to better forecasts than those based on least squares estimators.

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Approach

The binomial model was applied to FY81 through FY88 loss rate data arranged by 38 occupational fields (OCCF) and 9 pay grades (PGs). A beta prior distribution was assumed, and the empirical Bayes estimates of loss rates were generated using the method of moments. Loss forecasts based on the empirical Bayes estimates (transformed rates) were compared to forecasts based on the usual least squares estimates (untransformed rates).

Results

Four forecasting methods were applied to each of the 38 (OCCFs) x 9 (PGs) = 342 loss rate series: (1) the naive method that forecasts next year's rate with this year's rate, (2) a simple average of historical rates, (3) a weighted average method, and (4) an exponential smoothing method. Each method was applied to both the untransformed and transformed rates. A mean square error criterion was adopted to assess forecast accuracy. Table 1 summarizes the results. For example, when the naive method was applied, the transformed rates outperformed the untransformed rates in 261 of the 342 series or 76.4 percent of the time. Details of the FY89 effort will appear in a report being drafted entitled *Shrinkage Estimates of Marine Corps Enlisted Personnel Loss Rates.*

Also in FY89, some additional work on properties of empirical Bayes estimators was completed. This work was presented at the annual meeting of the American Statistical Association (ASA). A paper describing this research is to appear in the ASA 1989 proceedings of the Business and Economics Statistics section.

Table 1

Forecasting Performance of Empirical Bayes Estimates

Model	Losses %	Wins %	Ties %	Wins and Ties %
Naive	17.5	76.4	6.1	82.5
Simple Average	25.8	64.4	9.8	74.2
Weighted Average	28.1	64.2	7.7	71.9
Exponential Smoothing	24.7	68.6	6.7	75.3

Plans

Results from this project will transition into an existing 6.2 project *Marine Corps force management forecasting,* and an existing 6.3 project *Marine Corps enlisted planning system.*

Expected Benefit

Force management decisions impact billions of dollars in manpower appropriations. Since personnel loss forecasting is critical to successful force management, this effort commands considerable leverage. Benefits are expected to take the form of personnel plans that achieve skill and experience levels required to sustain readiness and avoid budget crises.

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Biography

Michael Nakada is an Economist in the Personnel Systems Department. He received his Bachelor of Arts in mathematics from Willamette University in 1972. He earned his PhD. in Economics from University of California at Santa Barbara in 1979. His research interests include labor supply, the minimum wage, and labor economic issues of the disadvantaged. He has published in the *Eastern Economic Journal*. He is a member of the American Economic Association and the Western Economic Association.

Military Recruit Quality and the Minimum Wage

Michael Nakada

The Congress is currently debating raising the federal minimum wage. Several states have already raised their minimum wages. Proposed federal legislation includes a subminimum "training" wage and a timetable for future minimum wage increases. Those affected by the minimum wage and the low end of the wage structure are the very same individuals the military actively recruits (i.e., 17-21 year old males and females). This effort develops an economic model that outlines the effects of increases in the minimum wage on the quantity and quality of military recruits.

Background and Problem

One of the key factors influencing an individual's decision to enlist in the military is his/her alternative civilian wage. For many of these young people, their potential civilian job will be their first full-time work, and will likely earn the minimum wage at the outset. Congress is currently debating raising the federal minimum wage. The last time it was increased was in January 1981. Moreover, current proposals to increase the minimum include a so-called "training wage" for those with less than 6 months work experience.

The increase in the minimum stirs debate over many economic issues. For example, because the minimum wage represents the lowest level in any wage structure, increasing it may mean increasing the wages of other employees. Here, "wage distance" between the various levels within a wage structure may need to be maintained. Other economists have argued that wage structures differ by level of education, experience, occupation, and industry. Therefore, changes in the minimum wage may have differential effects on certain labor groups.

The minimum wage does not apply to all economic sectors. That is, minimum wage coverage is not complete. For example, farm workers are not covered. With incomplete coverage, economists have debated the short- and long-run effects of increases in the minimum. One side of the debate argues that increases in the minimum wage drives workers out of the covered sector into the uncovered sector resulting in lower wages in the uncovered sector. The other half of the debate believes that the higher minimum wage attracts labor from the uncovered sector into the covered sector resulting in higher wages in the uncovered sector.

So what does this have to do with the military? First, the military competes with the private sector for the young people seeking those entry level jobs. Second, the military is one of the largest uncovered sectors. Thus, whether military wages rise or fall is crucial to military manpower supply. Third, in addition to the number supplied, an important issue for military training is the

supply quality. Under either theory, what is the quality of the labor in the uncovered sector? Does the military change formal school entrance requirements, alter training curricula, institute more remedial courses, lengthen course instruction, academically setback more students more often, or change weapons systems drastically? Some of these alternatives require changes in training resources. Last, the decline in the pool of nonprior service personnel has been well-documented. What is the interaction of this decline in labor source and the increase in the minimum wage?

Objective

The objective of this research is to develop an economic model of military supply quantity and quality and the proposed changes in the federal minimum wage.

General Approach

Because raising the minimum wage impacts many economic research issues, it will be necessary to determine their relationship to a military supply model. Little, if any, research on the minimum wage discusses its impact on the military. A review of the literature in this area will highlight the salient points that may relate to a military supply model.

A theoretical model that relates the enlistment supply of various groups to changes in the minimum wage structure will be developed. Changes in the minimum wage structure, in the form of increasing both the

regular minimum and subminimum, can be expected to affect both the level and quality mix of accessions. It should be noted that an economic model that includes a subminimum wage set below the regular minimum has yet to be developed.

Results

Because this research will not produce any empirical estimates, the model will suggest the methodology for developing an empirical model and will provide qualitative estimates of the likely direction of effect. If adequate estimates of military accession and training costs exist, calculations of changes in these costs as a result of changes in the minimum and subminimum wage will be generated.

Expected Benefit

The services could react passively to this change by accepting whatever the resulting level and mix of accessions happens to be, or the services could respond by altering their own policy instruments to contend with changes induced by the altered minimum wage structure. For example, the services could respond by varying pay, numbers of recruiters, advertising expenditures, enlistment bonuses, or quotas so as to keep fixed the number of high quality recruits. Computing the cost of doing so requires knowledge of (1) how each of these factors affects high quality enlistments and (2) the cost of changing each of these factors, as well as (3) the enlistment effects of changes in the minimum wage structure.

Biography

David G. Huntley is a Mathematical Statistician in the Manpower Systems Department. He earned a dual degree with distinction in French literature and mathematics, as well as an M.S. in Operations Research, from Stanford University. He is a member of Phi Beta Kappa. His research interests include applications of neural nets to forecasting, stochastic processes and optimization. His most recent work will be published in the proceedings of the 1990 conference on Advanced Computing for the Social Sciences.

Applications of Neural Net Technology to the Forecasting of Time Series

David G. Huntley

The purpose of this research is to discover whether a neural net approach provides more accurate forecasts than conventional techniques such as Box-Jenkins and ARIMA. The "turning point" problem in forecasting is defined as the inability of conventional forecasting methods to anticipate fluctuations in the data; they are excellent at predicting trends, but when the trends change, there is a delay in recognizing the change. The goal of the research is to examine whether neural nets are more sensitive to fluctuations in the data.

Background and Problem

The Navy's ability to meet its manpower needs is restricted by the size of the personnel budget. To keep personnel expenditures within budget, it's necessary to make accurate forecasts of the personnel inventory by grade and length of service (LOS). Forecasting methods need to be very accurate because small errors in a forecast of the Navy's 18 billion dollar military personnel budget can result in very large cost overruns.

One approach to this problem was developed in the 1970s. The Naval Personnel Pay Predictor, Enlisted (NAPPE) is a time series model of the enlisted population arrayed by LOS in years. Transition rates from LOS cell j to LOS cell j + 1 are forecast by the NAPPE m del, using Box-Jenkins techniques. NAPPE's predictions for mean LOS of the work force indicated a high degree of accuracy, and this is the measure we forecast by the neural net approach discussed in the next section. The accuracy of the forecasts, in any case, tends to diminish as the lead time increases.

Neural Net Forecast

The neural net model used was part of a software package by NeuralWorks. The forecasts were run on an IBM PC XT. Several network types were tried. These models use one or two "hidden layers" to generate an internal representation of the pattern to be matched. Such a configuration allows an arbitrarily difficult pattern association: any set of unambiguous input/output pairs can be learned.

The learning rule is basically an error-correction algorithm. The back-propagation paradigm used in the research uses a gradient descent method to find (hopefully) a global maximum in its search to optimize the match between input and output. One of the problems of a gradient descent algorithm in neural networks is that of setting the learning parameter. If the parameter is set too high, the network can oscillate--not converging at all. On the other hand, a small learning rate may make the network take a very long time to converge. Part of the problem was to discover an appropriate rate.

Due to limitations in the size and speed of the computer, the back-propagation algorithm used took an extremely long time to converge. After months of training, a suitable differentiation in cell size showed the process beginning to converge. Rapid improvisation and turnaround were impossible to achieve, so no definitive conclusions were reached.

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Huntley, D. G. (10 April 1990). *Neural nets: An approach to the forecasting of time series*. Paper presentation at the conference on Advanced Computing for the Social Sciences, Williamsburg, PA.

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APPENDIX A

PROJECT TRANSITIONS

Transitions

Independent Research

Experienced-based career development (0601152N.R000.06) will transition into exploratory development 6.2 research.

Application of machine intelligence to generate and test causal models on large data bases (0601152N.R0001.07) will be used in the 6.2 project *Training management expert systems* and in the exploratory development 6.2 project *Developing measures of effectiveness for knowledge discovery systems* (0602936N.RV36127.08).

Independent Exploratory Development

Forecasting with empirical Bayes estimators (0602936N.RV36127.05) will transition into an existing 6.2 project, *Marine Corps force management forecasting* and an existing 6.3 project, *Marine Corps enlisted planning system.*

APPENDIX B

PRESENTATIONS AND PUBLICATIONS

Presentations

Independent Research

Williams, D. (1989b). *ERPs and the suffix effect.* Poster presented at the annual meeting of the Psychonomic Society, Atlanta, GA.

Williams, D. & Lewis, G. (1989). Electrophysiology of human memory. Paper presented at the *2nd Navy Independent Research/Independent Exploratory Development Symposium*, White Oak, MD.

Independent Exploratory Development

Huntley, D. G. (April 1990). *Neural nets: An approach to the forecasting of time series.* Paper presented at the Conference on Advanced Computing for the Social Sciences, Williamsburg, VA.

Publications

Independent Research

Callahan, J., & Sorensen, S. (1989). *Rule induction for group decisions with statistical data, an example*. Submitted for publication.

Federico, P-A, (in press). Student cognitive attributes and performance in a computer-managed instructional setting. In R. F. Dillon & J. W. Pellegrino (Eds.), *Instruction: Theoretical and applied perspectives*. New York, NY: Praeger Publishers.

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APPENDIX C

AWARDS AND HONORS

Awards and Honors

Independent Research

The Cognitive Electrophysiology Project (Williams & Lewis) received funding from the Office of Naval Research for FY89 through the Navy Laboratory Participation Program.

This research was nominated for the best independent research project at the 2nd Navy Independent Exploratory Development Symposium. A commendation was given to Drs. Williams and Lewis by the Chief of Naval Research on 6 June 1988.

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13. ABSTRACT *(Maximum 200 words)*

The FY89 Independent Research/Independent Exploratory Development (IR/IED) programs began with a call for proposals in June 1988. Technical reviews were provided by supervisors and scientific consultants and six IR and four IED projects were funded. This report documents the results and accomplishments of these projects. It lists the projects active during FY89 and those supported in FY90. Two papers, one IR and one IED, chosen by the Technical Director as "Best Papers of 1989" are presented. Subsequent pages contain brief reports of research progress during FY89 written by the principal investigators of each project. This report lists the IR and IED projects that may have transitioned into other projects or into use by the Navy during the year. It itemizes the presentations and publications from IR and IED supported projects and presents awards and honors related to the projects.

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